★

ALLIS-CHALMERS

# ELECTRICAL REVIEW

December • 1939

Welding the anode plate of a mercury arc power rectifier.

# LOOK AT THE BOX SCORE!

| Utility | No. of Older Type Regulators in Service | Excitation in kva Required by Older Type | Excitation in kva Required if Step Type Had Been Installed | Possible Savings in kva with Step Regulators | Possible Savings in Dollars with Step Regulators |
|---|---|---|---|---|---|
| A | 18 | 270 | 90 | **180** | **1,350** |
| B | 1200 | 30,000 | 10,000 | **20,000** | **150,000** |
| C | 1800 | 31,500 | 10,500 | **21,000** | **160,000** |

**Get All the Facts! Read How Allis-Chalmers Step Regulators Can Save Money on Your System . . . by Cutting Wattless Current . . . by Giving You Longer Contact Life!**

Look at the box score! Check the facts on three of the hundreds of cases where step regulators would have meant big savings had they been available when the systems were laid out!

Challenging, aren't they? Here's the reason!

Step regulators require only about 1/3 the excitation current needed by older types of regulators. And Allis-Chalmers makes the only station-type step regulator for single-phase, 2400 and 4800 volt feeders on the market today!

Those figures in the right hand column represent the cost of fixed capacitors required to release system capacity for pay loads. But, even without buying fixed capacitors, this difference in kva (second from right) had to be supplied by the system. Think what a burden like this can mean to your system!

What's more, your maintenance costs are lower with Allis-Chalmers Step Regulators! All moving parts are completely immersed in oil . . . nothing to lubricate! And you don't have to replace contacts periodically!

For, at the time this advertisement was written, *there has not been a single contact replaced on an Allis-Chalmers regulator, due to deterioration from normal operation, since they were placed on the market six years ago!*

Find out about the savings Allis-Chalmers 5/8% Half-Cycling Step Regulators can bring to your system! Write for Bulletin 1183-A for all the facts on smoother regulation at lower cost.

A-1140

**INCREASE YOUR REVENUE WITH ALLIS-CHALMERS 5/8% HALF-CYCLING STEP REGULATORS**

TRANSFORMER DIVISION

# ALLIS-CHALMERS

MILWAUKEE · WISCONSIN

ALLIS-CHALMERS

# ELECTRICAL REVIEW

## C O N T E N T S



★


Vol. IV . . . . No. 4

December, 1939

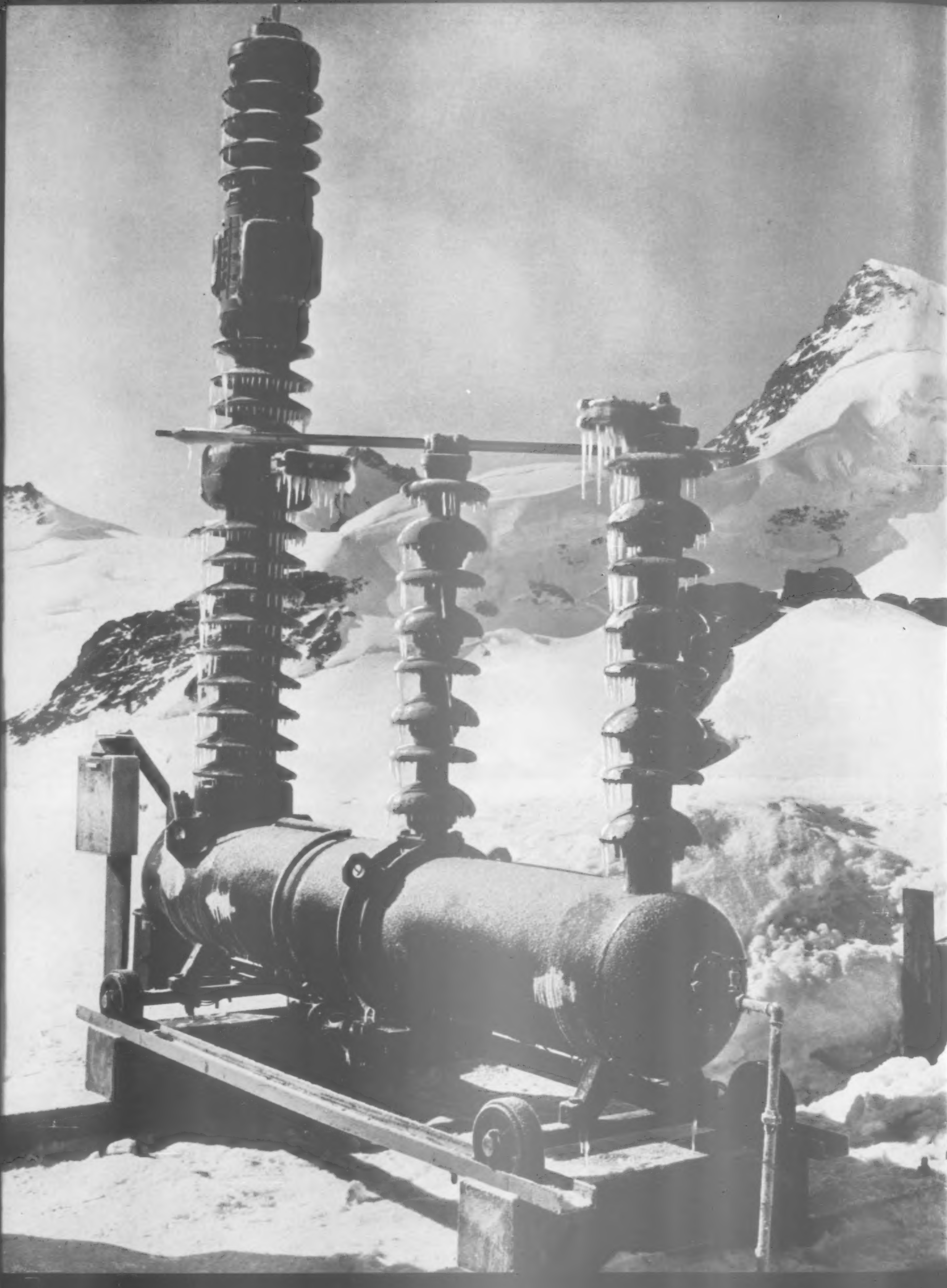
Allis-Chalmers Electrical Review



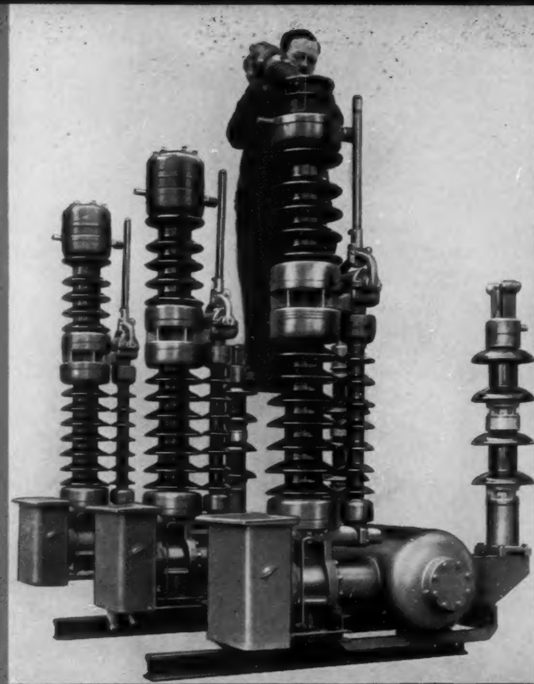


Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00. Address Allis-Chalmers Electrical Review, Milwaukee, Wisconsin.

Printed in U. S. A.



# A TYPICAL EUROPEAN HIGH-SPEED AIR BLAST CIRCUIT BREAKER



• W. S. Edsall, Assistant Manager
ELECTRICAL DEPARTMENT . . . ALLIS-CHALMERS MANUFACTURING CO.

• "Wars and rumors of wars" have had marked effects on European outdoor circuit breaker practice. The conventional outdoor oil circuit breaker requires a large amount of steel and uses a large volume of oil. Both of these materials are of paramount importance to a nation at war or preparing for war, particularly if the total iron ore and oil deposits within the boundaries of the nation concerned are insufficient, necessitating heavy imports of these materials.

Many European governments, because of their limited supplies of iron ore and oil, have imposed restrictions that have forced circuit breaker design engineers to curtail drastically the use of steel and oil in circuit breakers. This has resulted in the development of the porcelain-clad air blast or reduced oil volume breakers, which differ radically from the conventional oil circuit breaker.

An outstanding example of European outdoor air circuit breaker design* is the 150 kv, pneumatically operated, air blast breaker shown in Fig. 1. This type of breaker, while meeting the restrictions referred to, also provides a high degree of operating efficiency and so contributes toward improved system stability.

By using the prestored energy of compressed air for the twofold function of breaker operation and short circuit current interruption, very short interrupting and arcing times are obtained, as shown by Fig. 2, which depicts the operation of a 150 kv, 1,800,000 kva, high speed outdoor air blast breaker. The breaker was closed onto and then interrupted a 50 cycle short circuit current of 2450 amperes. The interrupting time, from energization of the trip coil to extinction of the arc, was under 2½ cycles, while the duration of the arc was considerably less than one-half cycle.

By referring to Fig. 1, it will be noted that the breaker consists of three individual poles comprising insulator columns, which together with a compressed air tank, control valve, and control mechanism for the disconnect switches are mounted on suitable base structures. Breakers up to and including 87 kv voltage rating are provided with a common air tank for each three-phase assembly. Above 87 kv each phase has a separate air tank. Air blast circuit breakers having a rated voltage of 150 kv or higher are provided with two arcing contacts in series.

* Designed and built by Brown Boveri Company, Baden, Switzerland.

ABOVE: Easy access to the contacts is one feature of air blast circuit breaker economy. AT LEFT: On Jungfraujoch, 11,350 feet above sea level, this breaker proved a consistent performer even during sub-zero temperatures and high wind velocities.

## • The design

The general design and construction of one specific type of outdoor air blast breaker is illustrated in Figs. 3, 4, and 5. In the diagrammatic section,

Fig. 4, a welded steel compressed air tank (1i) forms an integral part of the foundation framework, upon which the active parts are mounted. Compressed air at 225 lb G pressure is stored in the tank in sufficient volume for one or more interruptions. The tank has pipe connections to the compressed air supply and storage system of the station.

The compressed air tank is mounted horizontally. The main air blast valve (1e), located at the foot of the main air blast insulator column, is connected to one side of the tank by means of a large diameter horizontal pipe welded to the tank. The active elements of the breaker, consisting of the air blast column (2) and the disconnecting switch operating means, are attached to the horizontal pipe, the pipe being adequately supported since it is an integral part of the breaker foundation framework.

The arcing chamber (4) with its integral exhaust muffler or cooler is situated at the top of the main air blast column. The column is made up of two hollow insulators. The isolating or disconnecting switch (5) connected in series with the arcing contacts is hinged at a point midway between these two insulators. The disconnect stationary contacts (6) are supported by an insulator column (7) on the supporting framework. The various operating air valves are mounted within a weatherproof housing (8) at the foot of the main air blast column. Operation of the disconnects is obtained by the pneumatically induced rotational movement of the insulator support column (3) mounted vertically below the fulcrum point of the disconnect.

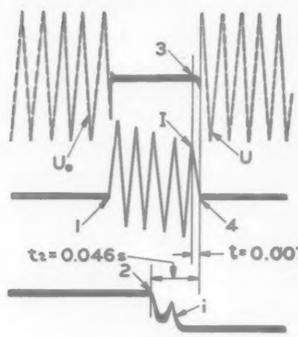



Fig. 2—Performance of 150 kv, 1,800,000 kva, high-speed Air Blast Circuit Breaker closing and clearing on short circuit. Top: Form of voltage, $U_0 = 142$ kv, $U = 130$ kv. Middle: Form of short circuit current, I = 2450 amp. Bottom: Current i taken by trip coil. 1—Initiation of short circuit current. 2—Beginning of excitation of trip coil. 3—Beginning of electric arc. 4—Extinction of arc. $t_1$—Inherent time of circuit breaker. t—Duration of arc.

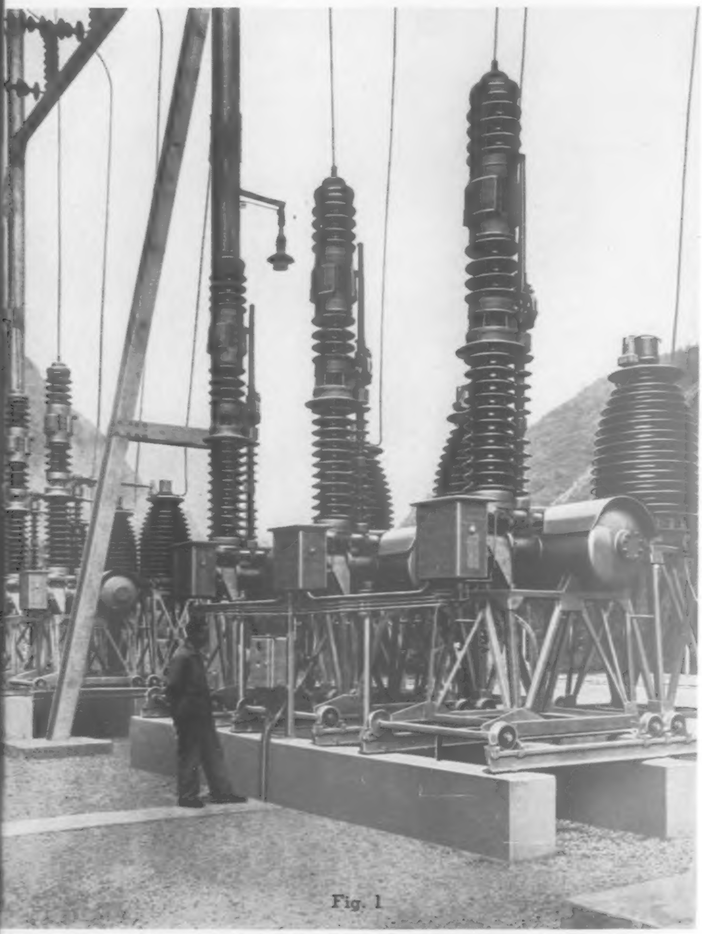


Fig. 1

## • The operation

To complete the circuit through the breaker, it is only necessary to close the disconnecting switches since the arcing contacts (21) and (22) are already held closed by the pressure of springs (23) as shown in Fig. 4.

Referring to Fig. 5, when the three coils (1c) operating the closing control valves are energized or when lever (E) is manually operated, valves (14) are opened. The opening of valves (14) admits compressed air to pistons (16), which then lift pilot valves (18). When pilot valves (18) open, compressed air passes from the main breaker air tank (1i) through ducts (20) to cylinders (1f) and thus exerts a torque on insulator columns (3) of Fig. 4. The insulator columns are provided with ball bearings, and the torque exerted on them is converted into a closing motion of the disconnecting switches (5), Fig. 4. This motion results in the closing of the circuit.

The circuit is first interrupted by pneumatically operating the arcing contacts within the air blast arcing chamber. After the interrupting arc has been extinguished, the disconnecting switches open under no load. The arcing contacts are then allowed to reclose.

Referring again to Fig. 5, when the three coils (1d) are energized, or when lever (A) is manually operated, control valves (15) open and admit compressed air to pistons to (17), which in turn lift pilot valves (19) and at the same time admit compressed air to plunger (52). The admission of com-

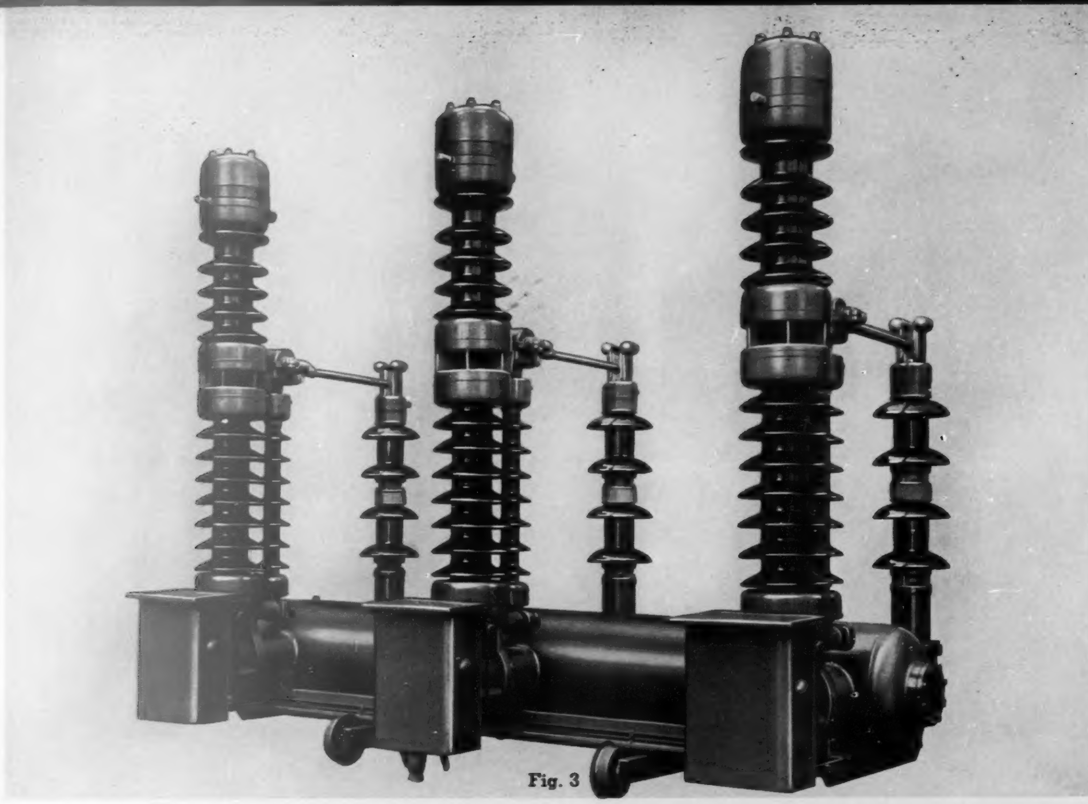


Fig. 3

pressed air to plungers (52) opens main air valves (1e) and allows high velocity compressed air to flow into the arcing chambers, effecting circuit interruption in the following manner:

By referring to Fig. 4, it will be seen that the admission of compressed air at high velocity to the arcing chamber will result in the separation of the movable contacts (22) from the stationary contacts (21). Immediately after the contacts separate, an arc is struck, but the flow of compressed air envelops the arc and, by forcible cooling and by the influence of the velocity and the high dielectric qualities of the compressed air, compels extinction of the arc at an early current zero.

As the compressed air is permitted to pass into the arcing chambers, it is also admitted to cylinders (1g), Fig. 5, causing the disconnecting switches to open under no-load conditions. The pneumatic control of the opening of the disconnecting switches is so arranged as to insure that the arcing contacts will be fully open and the arc positively extinguished before the disconnect switch contacts part.

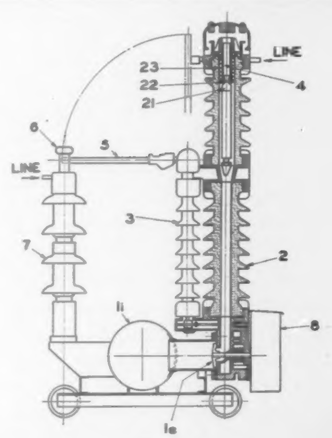



Fig. 4

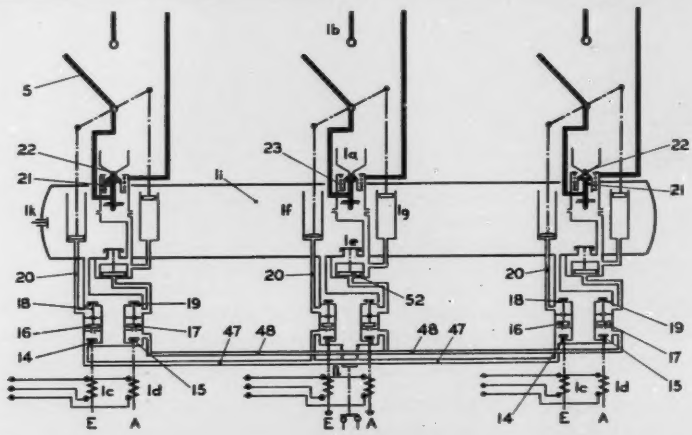



Fig. 5

After the disconnecting switch contacts are fully opened, the compressed air escapes from the arcing chamber through a vent and permits springs (23), Fig. 4, to reclose movable arcing contacts.

The advantages arising from the use of separate disconnecting and arcing contacts become fully apparent when the breaker is closed under short circuit conditions. The circuit is completed by closing the disconnecting switches. Then the tripping impulse transmitted by the overcurrent relays acting in conjunction with trip coils (1d), Fig. 5, and their associated control valves (15) causes instantaneous reopening of the circuit by means of the arcing contacts, since they are mechanically independent of the disconnecting switches. It follows that any arcing occurring during closing will not adversely affect the interrupting ability of the breaker.

Separation of the interrupting and disconnecting contacts also permits the use of a comparatively short movement of the arcing contacts, which produces a maximum air blast effect and so minimizes arc duration.

As the arc duration experienced is extremely short, very little contact burning is experienced, and renewal of contacts is therefore rarely needed. When servicing the contacts, it is necessary merely to remove a few screws in order to obtain complete access to the arcing contacts, as shown on page 5.

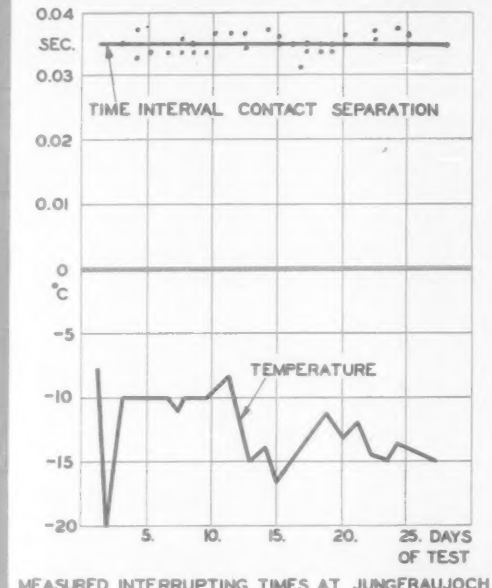


Fig. 6

## • Proof tests

Outdoor breakers must be capable of efficient operation under all climatic conditions. The consistent use of compressed air by the railroads over a long period of time, not only for braking purposes but also for rail switching operations, upon both of which functions depends the safety of millions of passengers, has been due to the availability of reliable pneumatic equipment. Nevertheless, as the experience there gained applies only partially in the case of air blast breakers, it was necessary to carry out thorough investigations concerning the ability of outdoor air blast breakers to operate under all conditions, special consideration being given both to frequent operation and to operation after a considerable period of inactivity.

Tests have proved that water condensation within the insulating columns due to varying climatic conditions is practically eliminated by an active venting of the inside spaces. Even during interruption no moisture is condensed, since the expanding compressed air absorbs moisture from its surroundings. Several thousand outdoor operations at all temperatures have proved these conclusions. As a final verification, steam was blown through a 150 kv breaker pole, causing heavy condensation within the columns. Interrupting tests at full operating potential were then made with entirely satisfactory results, due to the fact that only moisture-proof insulating materials are used in the construction of these breakers.

## • Low temperatures

Special attention has been given to the behavior of the breaker at extremely low temperatures. As the design of the air blast breaker is based on high pressure pneumatic operation, coupled with a small movement of parts, no operating difficulties were anticipated at low temperatures. Nevertheless, in order to obtain adequate verification, a 150 kv breaker, complete with its compressor plant, was installed and operated during February and March, 1938, on a mountain, at an altitude of 11,350 ft.

The test breaker is shown on location on page 4. The tests made on this breaker showed the following results:

a. No binding of the operating parts was encountered, even after long duration of subzero weather.

b. The breaker performed satisfactorily, even during and after snow storms at high wind velocity. The drift snow did not penetrate to the active inside parts of the breaker.

c. Oscillographic checking of interrupting times under varying weather conditions proved the consistent performance of the breaker, as is shown in Fig. 6.

d. The compressor plant, housed in a light wood casing, always operated satisfactorily.

e. Proper placement of the air piping prevented adverse ice formation.

During the test, various disconnecting switch arrangements were tried out. A disconnect design was finally evolved with which reliable closing and opening could be obtained, even with heavy ice formation on the contacts. The design of this disconnecting switch is such that the opening of the disconnect produces a breaking-loose action.

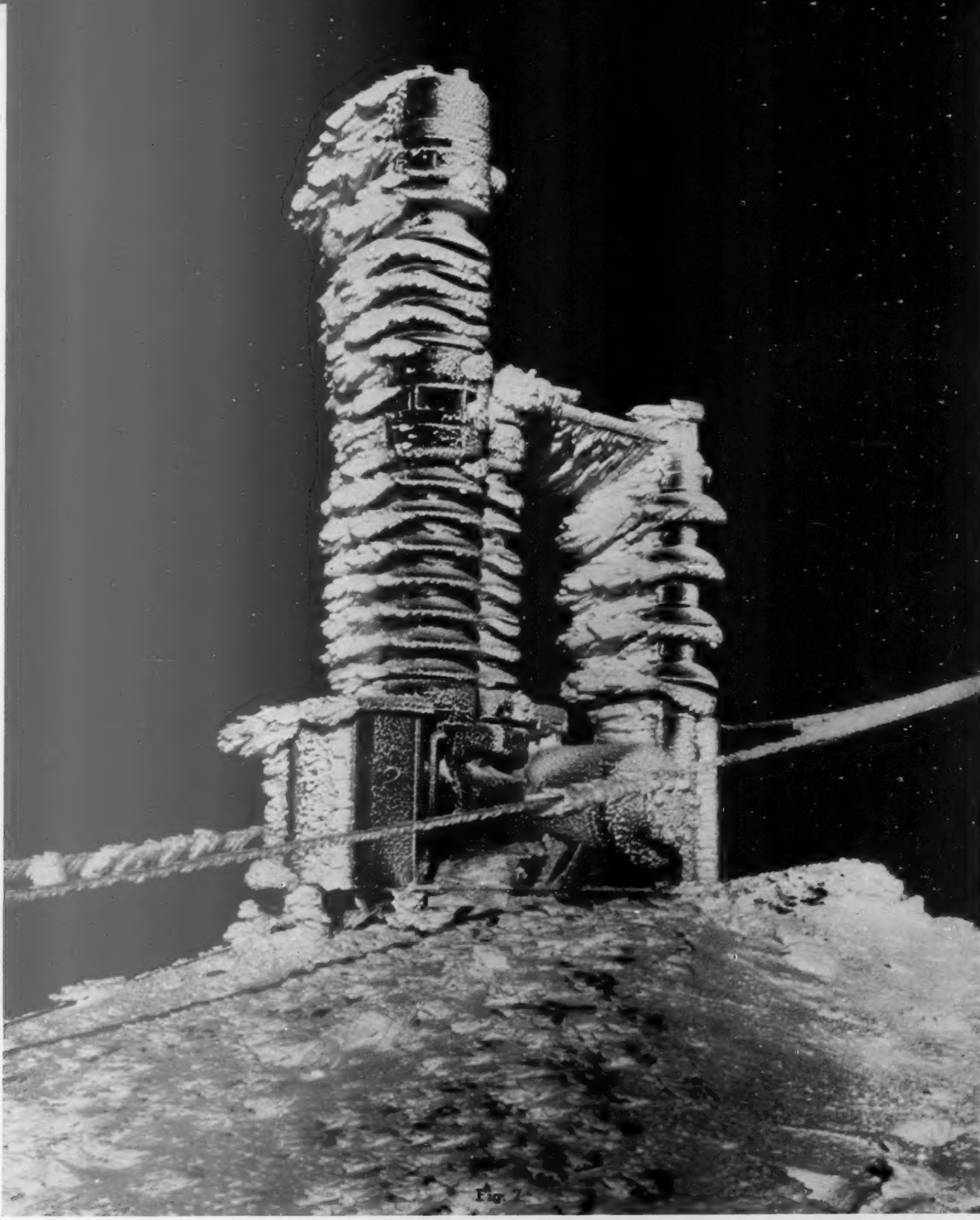


Fig. 7

Further tests were made during the winter of 1938-39. On this occasion the Swiss Meteorological Bureau was consulted to help in selecting a location providing maximum humidity and minimum temperature. The location finally chosen provided the fundamental conditions for maximum sleet formation on all breaker parts. The degree of sleet formation obtained is shown in Fig. 7, which depicts the state of the 87 kv test breaker on November 25, 1938. In view of the possibility of heavy ice formation, large area exhaust openings are provided on these outdoor breakers. In the case of the breaker shown in Fig. 7, the sleet formation on the top of the breaker was completely blasted away during the first opening.

## • Of general application

While this general type of construction was originally developed in order to economize on the utilization of steel and oil, it offers so many advantages that it is worthy of consideration even in this country, where both steel and oil are available in quantity.

# SIMPLE METHOD OF CALCULATING TRANSFORMER TEMPERATURE RISE UNDER VARIABLE LOADS

• W. C. Sealey
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

● The calculation of the temperature rise of a transformer carrying a variable load normally requires a series of involved calculations. The equations for short-time heating are equations which often involve the use of fractional exponents, and the equations are often exponential. However, if reasonable accuracy is to be secured, such equations must be used. Since the use of these equations cannot be avoided, a simplified method of making these calculations has been developed, employing a standard method of procedure together with specially developed charts and curves. By the simplified method described herein accuracy is not sacrificed, but the labor involved is reduced to a small fraction of that which would otherwise be required.

Whereas the conventional method requires a knowledge of the detailed weights of the various parts of the transformer, the simplified method has the added advantage of requiring only the nameplate data together with the usual data obtained from normal commercial tests.

## • General method

Although the method is described for oil-cooled transformers, since most large transformers are of this type, it may be used also for other types of transformers, as the general procedure is the same. For oil-insulated transformers, the method consists of dividing the temperature rise into two parts:

1. The temperature rise of the oil above the ambient temperature
2. The temperature rise of the copper above the oil.

AT LEFT: In the impulse laboratory, the windings of this 20,000 kva power transformer are tested under high voltage surges.

This procedure produces accurate results, because the copper attains its final temperature rise over the oil in a much shorter time than the oil requires to reach its final temperature rise over the ambient temperature. The term "ultimate temperature rise" is defined as the temperature rise that will be reached if a constant load is maintained continuously for sufficient time for the temperature to become constant.

From a large number of tests it has been found that for self-cooled transformers the ultimate oil temperature rise varies as the 0.8 power of the total loss. For water-cooled, forced-air, and forced-oil-cooled transformers, the ultimate oil temperature rise has been found to vary as the first power of the total loss.

## • Copper temperature rise

The ultimate temperature rise of the copper over the oil varies as the first power of the copper loss if the true or hot spot temperature difference between the copper and the oil temperatures is used. The temperature difference between the copper and the oil which is obtained on test by resistance measurement is actually the difference between the average copper temperature and the hot oil temperature. The true or hot spot temperature difference is higher than the value obtained by such a test.

The value of 10° C for the difference between the average copper temperature and the hot spot copper temperature at full load which has been established by the A. I. E. E. standards is a safe value for most transformers. Thus the hot spot temperature difference between the copper and oil at full load is approximately equal to 10° C plus the difference between the average copper and the hot oil temperatures.

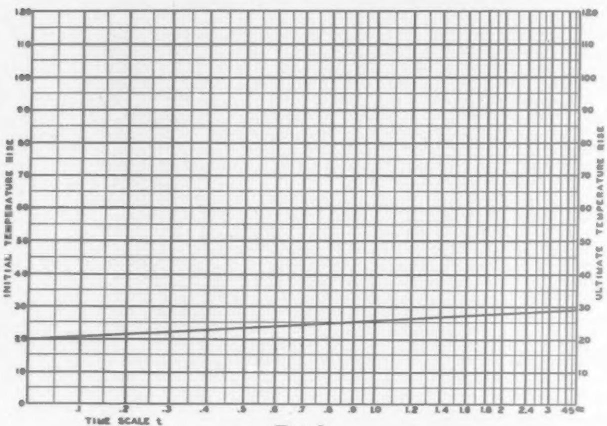


Fig. 1

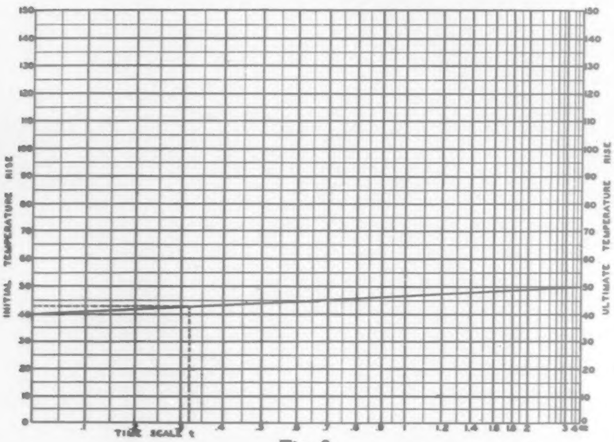


Fig. 2

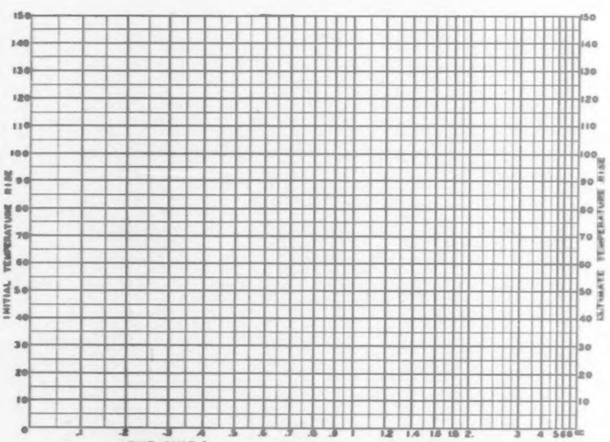


Fig. 3

## • Use of charts

If the temperature rise of a transformer is plotted against time on linear rectangular coordinate paper, the line will be curved. By using special non-linear coordinate paper of the proper type, a straight line may be obtained. The advantage of a straight line lies in the fact that it is necessary to determine only two points on it and to draw a straight line through those two points to obtain the complete curve of temperature versus time.

The non-linear coordinate paper used for transformers is shown in Figs. 1, 2, and 3. When these figures are used as follows, the curve of temperature versus time will be a straight line.

Figure 1 is to be used in charting the copper over oil temperature of any transformer and for the oil temperature rise of water-cooled, forced-air, and forced-oil-cooled transformers.

Fig. 2 is to be used in charting for increasing oil temperature rise of self-cooled transformers.

Figure 3 is to be used in charting for decreasing oil temperature rise of self-cooled transformers.

For all figures, t = the time on the abscissa = time in minutes divided by T, where T is a figure called the "thermal time constant," the value of which is determined as described in the following paragraphs.

## • Determination of T

Let $T_{cu} = T$ for copper

$T_o = T$ for oil

$U_{cu}$ = Ultimate temperature rise of copper over oil

$U_o$ = Ultimate temperature rise of oil over ambient

$H_{cu}$ = Thermal capacity of copper $= 2.93 \times$ lb copper or = approx 0.4 (lb core and coils)

$H_t$ = Thermal capacity of complete transformer $= 3.5 \times$ (lb core and coils) $+ 2.4 \times$ (lb case) $+ 80 \times$ (gal oil)

$W_{cu}$ = Watts copper loss

$W_t$ = Total watts loss

$J_1$ = Initial temperature rise

$W_1$ = Continuous watts required to produce an ultimate temperature rise of $J_1$

b is a constant taken from Fig. 6 corresponding to the ratio of $\frac{J_1}{U_o}$

In Fig. 1 (for copper over oil temperature of any transformer),

$$T_{cu} = \frac{U_{cu}\ H_{cu}}{W_{cu}}$$

In Fig. 1 (for oil rise of water-cooled, forced-air, and forced-oil-cooled transformers),

$$T_o = \frac{U_o\ H_t}{W_t}$$

In Fig. 2 (for increasing oil temperature rise of self-cooled transformers) when the initial rise $J_1 = 0$,

$$T_o = \frac{U_o\ H_t}{W_t}$$

In Fig. 2 (for increasing oil temperature rise of self-cooled transformers) when the initial temperature rise is greater than zero,

$$T_o = \frac{J_1\ H_t b}{W_t}$$

(For Fig. 2 when the value of $\frac{J_1}{U_o}$ is less than the lowest value shown on Fig. 6, the equation $T_o = \frac{U_o\ H_t}{W_t}$ can be used with only slight error.)

An alternate method for using Fig. 2 when the initial rise is not equal to zero is to use a value of $T_o = \frac{U_o\ H_t}{W_t}$, to draw the curve on Fig. 2 through the origin and the ultimate temperature, infinite time point, and to use a value of initial time not equal to zero but equal to the time corresponding to the initial temperature rise $T_1$ on the curve of Fig. 2.

In Fig. 3 (for decreasing oil temperature rise of self-cooled transformers) when the ultimate rise $U_o$ equals zero,

$$T_o = \frac{J_1\ H_t}{W_1}$$

In Fig. 3 (for decreasing oil temperature rise of self-cooled transformers) when the ultimate rise $U_o$ is greater than zero,

$$T_o = \frac{J_1\ H_t b}{W_t}$$

(For Fig. 3 when the value of $\frac{J_1}{U_o}$ is greater than the highest value shown on Fig. 6, the equation $T_o = \frac{J_1\ H_t}{W_1}$ can be used with only slight error.)

## • Determination of curve

When the proper chart has been selected and T determined for it, the two points through which the straight line is to be drawn are determined. For all figures the two points through which the straight line is commonly drawn are the initial temperature rise ($J_1$), zero time point, and the ultimate temperature rise (U), infinite time point.

These points can then be plotted on the chart and a straight line drawn through them. The temperature rise corresponding to a given time T or the time required to reach a certain temperature rise can be read from the curve.

In addition to the use of the charts a tabular form such as shown in Fig. 5 conserves time and helps to eliminate errors. This form has been partially filled in with values taken from the following example as the values were calculated.

## • Example

Given a self-cooled transformer and the following data applying to it:

Core loss — 10,000 watts

Copper loss at full load and 75° C — 25,000 watts

Oil temperature rise with full load continuously by test — 40° C

Copper temperature rise at full load by resistance by test — 50° C

Weight core and coils — 18,000 lb

Weight case — 15,000 lb

Quantity of oil — 1,500 gal

REQUIRED: The hot spot temperature rise with 120 percent load for one hour following full load continuously.

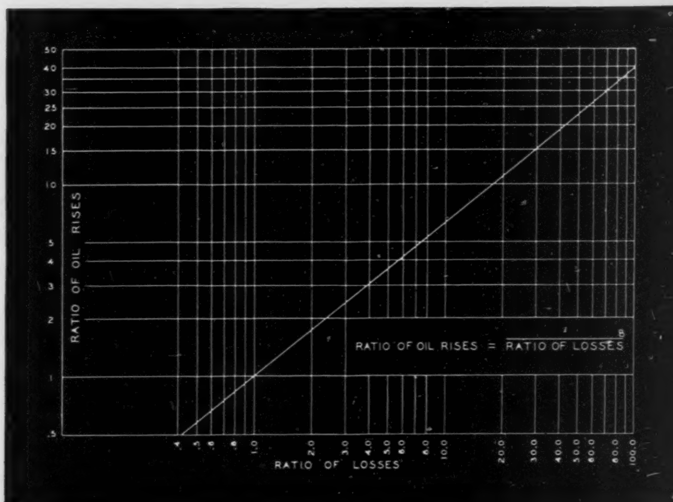



Fig. 4

**SOLUTION:** The tabulation of Fig. 5 is filled in first with the given data and then with the values of the various quantities as they are calculated.

The weight in pounds of the core and coils and the case, gallons of oil, core loss, copper loss, and copper rise over the oil for 100 percent load are total loss for 100 percent load, oil rise and hot spot placed on the table. The HOT SPOT difference between copper and oil temperature $=10^\circ+50^\circ-40^\circ=20^\circ$ C.

The core loss at 120 percent load is 10,000 watts (the same as at any other load); the copper loss varies as the square of the load and is therefore equal to $\left(\frac{120}{100}\right)^2\times 25{,}000=36{,}000$ watts.

The total loss at 120 percent load is equal to the sum of the core and copper losses, or $10{,}000+36{,}000=46{,}000$ watts.

The ultimate oil temperature varies as the 0.8 power of the loss, since this is a self-cooled transformer. The ratio of the loss at 120 percent load to the loss at full load $=\frac{46{,}000}{35{,}000}=1.314$. From Fig. 4 the oil rise ratio corresponding to a loss ratio of 1.314 is 1.24. The ultimate oil rise for 120 percent load $=1.24\times 40=49.6^\circ$ C. Since this is a self-cooled transformer with increasing oil rise, the curve will be a straight line if plotted on Fig. 2. The ratio of $\frac{J_1}{U_o}=\frac{40}{49.6}=0.806$. From Fig. 6, the value of b corresponding to this ratio is 0.99.

$$T_o=\frac{J_1\ H_t b}{W_t}=\frac{40\times 219{,}000\times 0.99}{46{,}000}=188$$

The two points through which the straight line is drawn on Fig. 2 are the 40° (initial temperature rise), zero time point, and the 49.6° C (ultimate temperature rise), infinite time point. The time t $=\frac{60}{188}=0.319$. The temperature rise corresponding to this point on Fig. 2 is 42.5° C, which is equal to the final oil rise at the end of one hour.

For the copper rise over the oil, Fig. 1 is used.

$$T_{cu}=\frac{U_{cu}\times H_{cu}}{W_{cu}}=\frac{20\times 7200}{25{,}000}=5.75$$

(Note: Since $\frac{U_{cu}}{W_{cu}}$ is constant for all loads and $H_{cu}$ is a constant, $T_{cu}$ will be the same for all loads for a given transformer.)

The points used to determine the straight line on Fig. 1 are the 20° C (initial temperature rise), zero time point, and the 28.8° C (ultimate tempera-rise), infinite time point. This line is drawn on Fig. 1. The final time t is equal to

$\frac{\text{time in minutes}}{T_{cu}}=\frac{60}{5.75}=10.4$. The temperature rise over the oil corresponding to this time on Fig. 1 is 28.8° C. The total hot spot copper temperature rise is equal to $42.5+28.8=71.3$. The actual hot spot temperature is the sum of the hot spot rise and the ambient air temperature. If the ambient temperature is 20° C, the hot spot temperature will be $20^\circ+71.3^\circ$, or 91.3° C.

The safe hot spot temperature of a transformer for recurrent loads is generally taken as 95° C for conservative practice. Consequently, the proposed loading will be safe for this transformer with 20° C ambient or with any ambient up to $(95-71.3)$ or 23.7° C.

## • Other applications

The procedure to be followed for other transformers and other conditions of loading is the same. The only precaution necessary is that the proper charts be selected.

Rating.............................. Serial No..................................

| | | | | |
|---|---|---|---|---|
| Lb Copper (if known) | ............ | $\times 2.93=$ | ............ | $= H_{cu}$ |
| Lb Core and Coils | 18,000 | $\times 0.4^*=$ | 7,200 | $=^*H_{cu}$ |
| | | $\times 3.5=$ | 63,000 | $= H_1$ |
| Lb Case | 15,000 | $\times 2.4=$ | 36,000 | $= H_2$ |
| Gal Oil | 1,500 | $\times 80.0=$ | 120,000 | $= H_3$ |
| Total thermal capacity $=H_1+H_2+H_3$ | | $=$ | 219,000 | $= H_t$ |

* Approx. value — Use when lb of copper are unknown.

| | | | | |
|---|---|---|---|---|
| | Percent Load | 100 | 120 | ______ |
| | Watts Core Loss | 10,000 | 10,000 | ______ |
| | Watts Copper Loss 75° C | 25,000 | 36,000 | ______ |
| | Watts Total Loss $W_t$ | 35,000 | 46,000 | ______ |
| Oil over Ambient | Time in Minutes | Continuous | 60 | ______ |
| | °C Initial Temp Rise $J_1$ | | 40 | ______ |
| | °C Ult. Temp Rise $U_o$ | 40 | 49.6 | ______ |
| | b (from Fig. 6) | | 0.99 | ______ |
| | $T_o$ | | 188 | ______ |
| | Time t | | 0.319 | ______ |
| | Final Temp Rise | | 42.5 | ______ |
| Copper over Ambient | °C Initial Temp Rise | | 20 | ______ |
| | °C Ult. Temp Rise $U_c$ | 20 | 28.8 | ______ |
| | $T_{cu}$ | 5.75 | 5.75 | ______ |
| | Time t | | 10.4 | ______ |
| | Final Temp Rise | | 28.8 | ______ |
| | Total Temp Rise | | 71.3 | ______ |

Fig. 5

Where loading over a repeating 24-hour cycle is given and the maximum temperature rise is required, a convenient method of procedure is to divide the load up into blocks of constant load for a given time so that the rms value of the load for the block is the same as the rms value of the actual load. An estimate is made of the oil rise for the starting point, and the temperature rise is calculated for each block successively using for a starting temperature rise the value obtained from the preceding calculation.

If the calculated temperature at the end of 24 hours is not sufficiently close to the assumed starting temperature, a different value is assumed for the starting temperature; and the process is repeated until a closed curve results. An alternate method and one which is usually satisfactory is to continue the curve until it comes sufficiently close to the first curve.

## • Value of method

By the use of such a simplified method the labor of calculating the temperature rise of a transformer carrying a variable load can be greatly reduced. The general simplified method described is applicable not only to oil-insulated transformers but also to other types of apparatus, including dry type transformers.

## • Appendix

The foregoing procedure will give temperature rises which are either correct or slightly high for practically any transformer.

For many transformers, however, the ultimate temperature rise of the copper over the oil ($U_{cu}$) varies more closely as the 0.8 power of the loss than as the first power of the loss. For such transformers, the following procedure will produce more accurate results and lower calculated values of temperature rise.

## • Use of charts

(When the Copper Over Oil Temperature Varies as the 0.8 Power of the Loss.)

The oil temperature rise is calculated as given heretofore. The only difference is in the method of calculating the rise of the copper over the oil. Fig. 2 is to be used in charting for increasing copper over oil temperature.

Figure 3 is to be used in charting for decreasing copper over oil temperature.

In Fig. 2 (for increasing copper over oil temperature) when the initial rise $J_{1(cu)}$ of the copper over the oil$=0$

$$T_{cu}=\frac{U_{cu}\,H_{cu}}{W_{cu}}$$

In Fig. 2 (for increasing copper over oil temperature) when the initial rise $J_{1(cu)}$ of the copper over the oil is greater than zero, $T_{cu}=\frac{J_{1(cu)}\,H_{cu}\,b}{W_{cu}}$ where b is taken from Fig. 6 as the value of b corresponding to $\frac{J_{1(cu)}}{U_{cu}}$ as ordinate. (For Fig. 2 when the value of $\frac{J_{1(cu)}}{U_{cu}}$ is less than the lowest ordinate value shown on Fig. 6, the equation $T_{cu}=\frac{U_{cu}\,H_{cu}}{W_{cu}}$ can be used with only slight error.)

In Fig. 3 (for decreasing copper over oil temperature) when the ultimate rise of the copper over the oil equals zero, $T_{cu}=\frac{J_{1(cu)}\,H_{cu}}{W_{1(cu)}}$.

In Fig. 3 (for decreasing copper over oil temperature) when the ultimate rise of the copper over the oil is greater than zero, $T_{cu}=\frac{J_{1(cu)}\,H_{cu}\,b}{W_{cu}}$ where b is taken from Fig. 6 as the value corresponding to $\frac{J_{1(cu)}}{U_{cu}}$ as ordinate.

(For Fig. 3 when the value of $\frac{J_{1(cu)}}{U_{cu}}$ is greater than the highest ordinate value shown on Fig. 6, the equation $T_{cu}=\frac{J_{1(cu)}\,H_{cu}}{W_{1(cu)}}$ can be used with only slight error).

The procedure for the use of the charts after $T_{cu}$ has been properly determined is the same as described previously.

NOTE: A limited quantity of enlarged copies of Figs. 1, 2, and 3 can be obtained from the Allis-Chalmers Electrical Review.

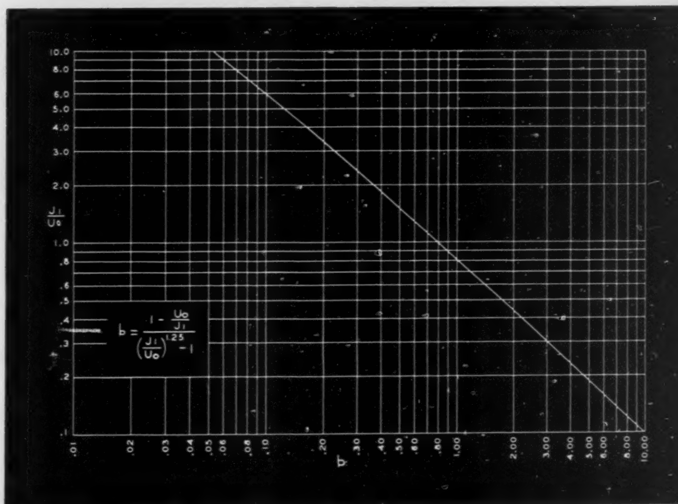



Fig. 6

# HOW CURRENT TRANSFORMER APPLICATION AFFECTS DESIGN

• R. W. Beard
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

Fig. 1—Outdoor Wound Type

● There are three general types of construction employed in the designs of modern current transformers:

1. Wound type
2. Through type
3. Bar type

All three types have in common a wound secondary and a laminated steel core. The classification or type of design of a current transformer is determined by the construction of its primary winding. If the primary is wound in the conventional manner, the transformer is of the first type of construction. If the transformer does not have a primary but has a window through which the conductor of the circuit to be metered is inserted, the design is of the second type. The bushing type current transformer comes under this second classification. In the third type — the bar type — a primary consisting of one turn or bar is inserted and fastened into the window. Figs. 1 to 6 illustrate indoor and outdoor type units coming under each classification of design and represent the forms taken in modern construction for the lower voltage classes.

On large interconnected systems either the through or bar type construction is selected to take care of heavy fault currents which may occur. Current transformers located at or near generating stations must be capable of withstanding, without damage, tremendous short-time overcurrents. For such applications the wound primary type unit is at a distinct disadvantage, as it is susceptible to two types of failure under such circumstances — thermal and mechanical. The duration of the fault on systems with modern protective apparatus is frequently short, in which case a normally designed current transformer may be satisfactory from a thermal standpoint. If not, larger conductors must be employed, as all heat generated is stored in the windings since the time intervals involved are so short that no appreciable radiation of heat can take place.

The instantaneous value of the fault current may be high enough to disrupt the wound primary because of the large mechanical forces developed. The mechanical disruptive forces are proportional to the square of the number of turns in the primary. Therefore, from the point of view of stability the fewer the primary turns, the better; and the through type or the bar type construction meets this requirement. However, there may be a practical limitation in the reduction of primary turns due to accuracy requirements. Accuracy over a wide range of secondary burdens may be necessary; and unless the normal primary current is relatively high, there may be insufficient ampere-turn capacity to produce the required performance.

The selection of the proper design to be used, therefore, becomes a problem of weighing the importance of accuracy against mechanical and ther-

Fig. 2—Indoor Wound Type

mal strength. For example, if a standard wound type current transformer rated 400 to 5 amp has four primary turns, 1600 amp turns would be produced, which would be ample, in conjunction with a normal core, to provide high ratio and phase angle accuracy over a range of burdens up to approximately 50 volt-amp. This transformer would withstand an instantaneous current as high as 68,000 amp. If higher fault currents can be expected, a three-turn primary design might be used. The use of this construction would increase the instantaneous current rating to approximately 120,000 amp. The accuracy would be reduced considerably unless other steps were taken in the design to offset the reduction in ampere turns.

Two methods are open to compensate partially for this reduction:

1. The use of a larger core of the same material (silicon steel)
2. A change to a nickel steel core with its higher permeability

Since compactness of design is becoming of greater importance in the design of current transformers which must fit into cubicles and small switchboards, size limitations may eliminate method 1 even if the cost consideration is overlooked. Method 2 is also objectionable because nickel steel is more costly than silicon steel, and a moderate size core saturates considerably quicker. These objections usually discourage the use of nickel steel, particularly for relay applications.

In general, therefore, the most suitable type of current transformer for a particular application depends upon the comparison of the maximum errors which can be tolerated in meter readings with the increased cost and increased dimensions which are practical in construction.

As stability, compactness, and freedom from winding weakness are steadily becoming more and more important in design considerations of current transformers, the bar type and through type units are generally preferred to the wound type of construction except in cases where the chief attribute of the wound type — that of higher accuracy over a wide range of burdens — is essential.

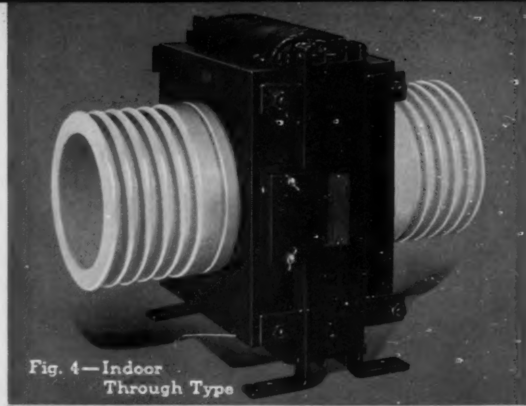


Fig. 4—Indoor Through Type

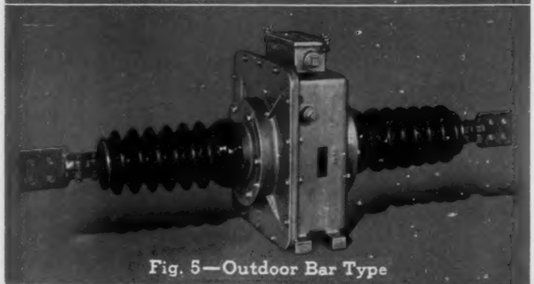


Fig. 5—Outdoor Bar Type

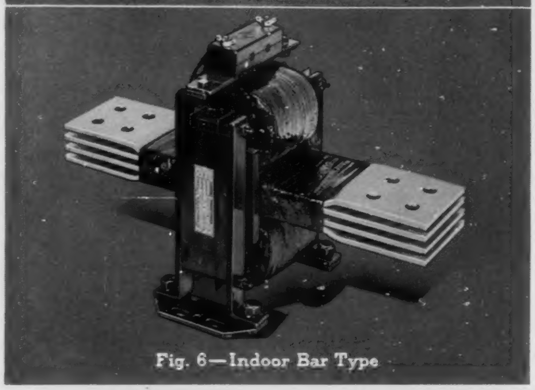


Fig. 6—Indoor Bar Type

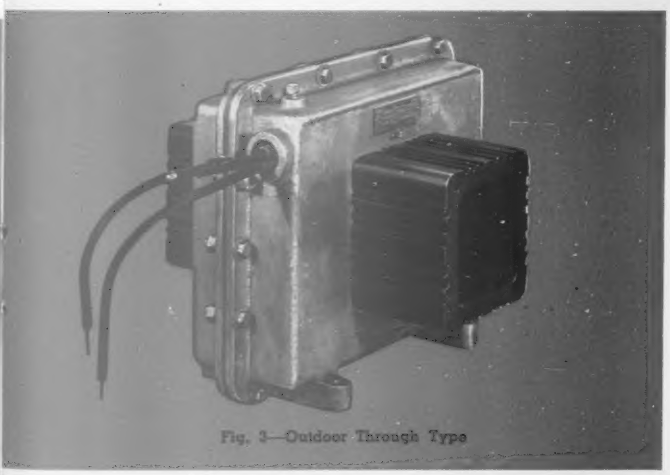


Fig. 3—Outdoor Through Type

For the heavier current ratings, approximately 1000 amp and above, all of the advantages of both types can be obtained by using either the bar or through type design. For lower current ratings, it is frequently possible to satisfy accuracy requirements in the one-turn primary design by compensating the windings for the best accuracy at the single burden for which the installation was originally made.

ON FOLLOWING PAGES: Mitchell Dam, Coosa River, Alabama.

# FORGINGS FOR STEAM TURBINE ROTORS

• Hans Dahlstrand, Engineer-in-Charge . . . STEAM TURBINE DEPARTMENT
• H. J. Stein, Director of Research, Chemistry, and Metallurgy
• ALLIS-CHALMERS MANUFACTURING CO.

● The rotating parts of steam turbines, operating at high speeds with resultant high stresses and at the same time exposed to high temperature steam, must be not only properly designed but also made of materials suitable for the high stresses and temperatures to which they are exposed during operation.

In the early development of the steam turbine, the steam conditions, pressures and temperatures were quite moderate; consequently, the demand for high grade steel in the rotating parts did not then exist. This was fortunate for the steam turbine designer, because at that time suitable steel was not available.

But, as the power plant designer demanded increasingly greater efficiency from the steam turbine equipment, it was necessary not only to increase the steam pressures and steam temperatures but also to design and build more efficient and larger capacity steam turbines. These requirements necessitated materials having greater physical strength as well as other physical qualities that would make them satisfactory for operation at high temperatures during long periods. The success with which metallurgists have developed satisfactory steels is indicated by the successful operation, at high pressures and temperatures, of many large steam turbine units.

Still higher temperatures are contemplated, probably requiring better steels than are now available and perhaps also different designs of the steam turbine.

In the early steam turbines built about 1906, the specification for the steel, both for the shaft and rings, required that:

"Forgings to be of acid open-hearth carbon steel (free from nickel) containing not over 0.05 percent each of phosphorus and sulphur. Forging to be made by a hydraulic press. Reduction in cross-sectional area from bloom to final forging, not less than 40 percent at largest diameter. Forging to be thoroughly annealed in recognized annealing furnace, both before and after rough machining. After each annealing, forgings to remain in furnace until cold. Second annealing to take place after final machining, which is to be within one-eighth of an inch of finished surfaces as given on requisition. This one-eighth of an inch to be left on inside of surfaces, the same as on other surfaces.

"Test pieces to be taken from full-sized prolongation on each end of forgings, half way between outside and inside. Axis of test pieces to be parallel to axis of forgings. Test pieces, taken after final annealing, cold machined only, to show the following characteristics:

"Longitudinal Test

"Ultimate tensile strength, not less than 65,000 lb per sq in.

"Elastic limit, not less than 32,500 lb per sq in.

"Elongation in two inches, not less than 25 percent.

"Contraction of area, not less than 35 percent.

"Outside and inside diameters must be true and concentric with axis."

The above specification is given here to indicate that the steam turbine designer early recognized the importance of a stable structure in the material. Even with the low temperatures used 30 to 40 years ago, the steam turbine spindles had to be thoroughly and uniformly annealed in order to avoid distortions. There was no steel available other than plain carbon steel that was considered suitable for steam turbine spindles. While alloy steels using nickel as an alloying element had appeared, it was not considered reliable, as indicated by the statement that the forging must be free from nickel. At that time, when nickel was first used, serious difficulties were experienced with forgings made with nickel.

During the years that have elapsed since the building of steam turbines was first undertaken, there have been steady and continuous changes in operating conditions with higher pressures and temperatures. These changes in operating conditions have made it necessary to use steels of entirely different characteristics. The steel makers have in this respect kept pace with the demand; and with the use of the numerous alloying elements now available, and with exact knowledge of the proper treatment of steel, they are now producing forgings suitable for the various types of steam turbines.

Naturally, the selection of the proper materials by the design engineer can be determined only by consultation between the engineer and the metallurgist who is responsible for the detail specifications covering the chemical analyses, physical characteristics, and heat treatments. It can readily be seen that only those thoroughly familiar with all the processes involved in the making and the treatment of steels are competent to specify all the details in order that the finished products shall be satisfactory for the intended purposes.

The very first requirement in selecting the material is that it be stable. This means that the steel in a turbine spindle must be uniform throughout, both as to analysis and heat treatment, and must be free from internal stresses. The importance of having this stable condition can readily be seen when it is realized that during operation the turbine spindle is subjected not only to varying temperatures from one end to the other but also to variation in temperature due to load changes. If internal stresses exist, the spindle will distort with temperature changes, causing unbalance and consequent vibration. It is not possible to balance such a spindle, as the magnitude of the distortion is dependent upon the temperature. Likewise, if the chemical analysis of the steel is not uniform, there will be some distortion because of change in the expansion coefficient.

For the high temperatures now adopted in steam power plants, there is another very important characteristic that the steel must have. At these high temperatures and the attendant stresses, there is a slow and steady increase in the size of parts in the direction of the stress. This increase in dimension is called "creep." The rate of creep is dependent on the composition and characteristics of the material as well as the temperature and magnitude of the stresses. For a given material with a constant temperature, the creep increases as the stress increases.

It is therefore of great importance that the creep characteristics of the materials used be known, as the design is largely influenced by the materials available. The stresses adopted in the design must be such that parts subjected to creep will be satisfactory over a certain period of time without the necessity of replacement. Naturally, the allowable rate of creep can differ in various parts, as some parts may have several times the creep of others, so long as the life of the equipment is not shortened. Turbine spindles must maintain their size and shape very closely, and therefore it is customary to design them so that the rate of creep will not exceed 0.1 percent in 100,000 hours.

To give a more complete picture of the development of steel forgings for steam turbine spindles, specifications for steels in successive periods of time are given below, indicating the increasing demand for steels with higher physical characteristics.

In the first period the specifications conformed to that given in the early part of this paper. During the period from about 1912 to 1920, the characteristics specified were as follows:

| Chemical Analysis | |
|---|---|
| Carbon | 0.40 – 0.50 |
| Manganese | 0.40 – 0.70 |
| Silicon | 0.15 – 0.25 |
| Sulphur | 0.055 max |
| Phosphorus | 0.045 max |

Physical properties common with this straight carbon steel were, as annealed:

Tensile strength
70,000 – 80,000 lb per sq in.

Yield point
35,000 – 40,000 lb per sq in.

| | |
|---|---|
| Elongation in two inches | 25 – 30 percent |
| Reduction in area | 30 – 35 percent |

During the period 1920 to 1932, to meet the increased demand for more efficient power plants by the utilization of higher pressures and temperatures, it became necessary to develop still better materials for forgings suitable for these more severe conditions. The metallurgists were confronted with the problem of obtaining steels of greater tangential and radial strength.

It was readily recognized that, in forgings of diameters ranging from 25 inches to 45 inches, it was impossible to obtain higher radial and tangential physical results from the straight carbon types of steels without a liquid quench, with the result that materials bearing one or possibly two alloys were investigated and used.

Improved physical properties were obtained by using a furnace or air-cooling treatment. Then the engineer could be assured of quite uniform physical characteristics throughout the body of the forging although it was dangerous to liquid-quench any section exceeding seven inches in diameter or wall thickness.

The materials used at this stage of progress were carbon vanadium steels of the following composition:

| | |
|---|---|
| Carbon | 0.40 – 0.50 |
| Manganese | 0.40 – 0.70 |
| Silicon | 0.15 – 0.25 |
| Sulphur | 0.055 max |
| Phosphorus | 0.045 max |
| Vanadium | 0.07 – 0.17 |

Physical test characteristics, as annealed:

| | |
|---|---|
| Tensile strength | 75,000 – 80,000 lb per sq in. |
| Yield point | 45,000 – 50,000 lb per sq in. |
| Elongation in two inches | 22 – 25 percent |
| Reduction in area | 35 – 45 percent |

About 1932, demands began to come for power plant operations at 1200 lb per sq in. steam pressure and 800 –1000 F steam temperature. With these operating conditions it was necessary to take into consideration the creep of materials at elevated temperatures in order to obtain satisfactory operation of the equipment over long periods of time. Metallurgists in the oil industry had been searching for materials capable of operating under high stresses, pressures, and temperatures encountered in oil refining and cracking processes, and their findings made the path of the turbine metallurgist easier.

The research of materials evolved several alloys, namely, carbon-molybdenum-vanadium, nickel-molybdenum, and chromium-nickel-molybdenum. Each

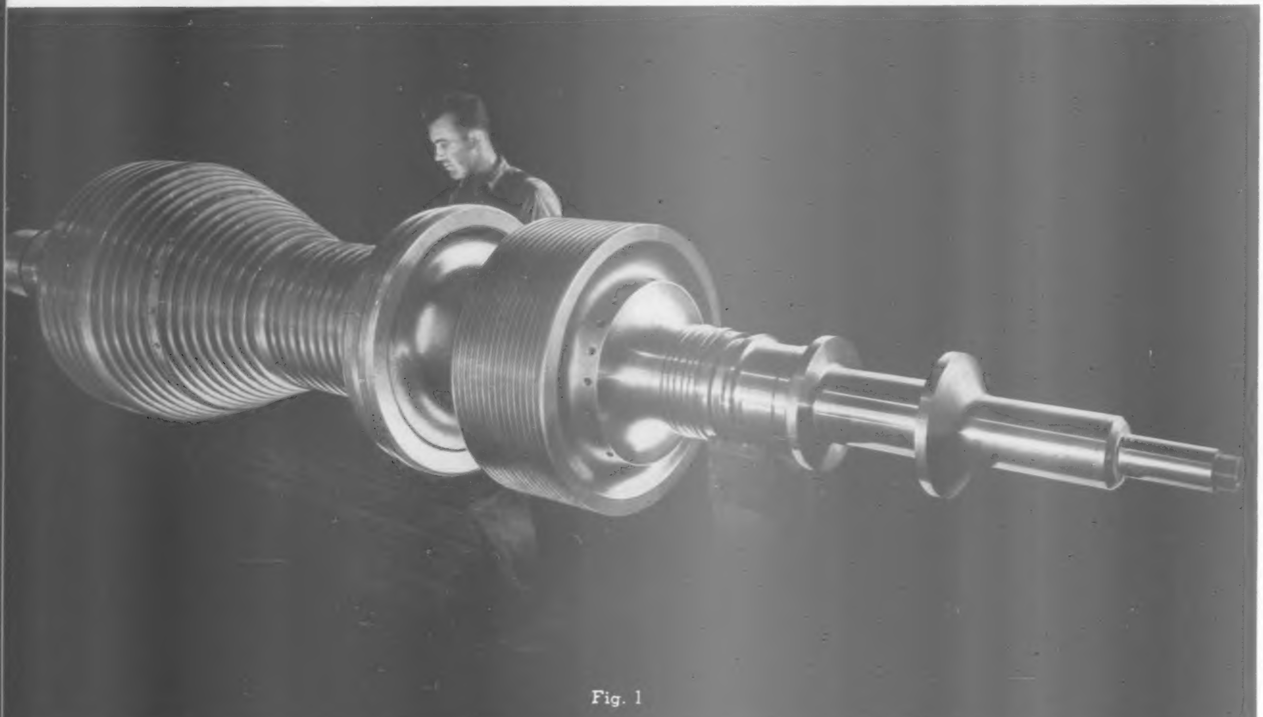


Fig. 1

of these materials has resistance to creep characteristics ranging from operating temperatures of from 800 – 1100 F.

Composition and physical characteristics are as follows:

Carbon-Molybdenum-Vanadium

| | |
|---|---|
| Carbon | 0.30 – 0.40 |
| Manganese | 0.80 – 1.00 |
| Silicon | 0.25 max |
| Sulphur | 0.050 max |
| Phosphorus | 0.050 max |
| Vanadium | 0.07 – 0.17 |

| | |
|---|---|
| Tensile strength | 75 000 lb per sq in. |
| Yield point | 45 000 lb per sq in. |
| Proof stress | 40,000 lb per sq in. |
| Elongation in two inches | 25 percent |
| Reduction in area | 40 percent |

Nickel-Molybdenum

| | |
|---|---|
| Carbon | 0.30 – 0.39 |
| Manganese | 0.65 – 0.75 |
| Nickel | 2.50 |
| Molybdenum | 0.40 – 0.45 |

| | |
|---|---|
| Tensile strength | 80,000 – 85,000 lb per sq in. |
| Proof stress | 50,000 – 60,000 lb per sq in. |
| Elongation in two inches | 15 – 20 percent |
| Reduction in area | 25 – 30 percent |

Chromium-Nickel-Molybdenum

| | |
|---|---|
| Carbon | 0.35 – 0.45 |
| Manganese | 0.50 – 0.80 |
| Chromium | 0.50 – 0 80 |
| Molybdenum | 0.30 – 0.40 |
| Nickel | 1.50 – 2.00 |

| | |
|---|---|
| Tensile strength | 105,000 lb per sq in. |
| Yield point | 70,000 lb per sq in. |
| Proof stress | 65,000 lb per sq in. |
| Elongation in two inches | 17 percent |
| Reduction in area | 40 percent |

These physical characteristics are minimum values, and in a great many cases the actual results exceed those listed.

## • Ingots for forging

Ingots to be used in making forgings for steam turbine spindles and rotors may be made by either the acid or basic open-hearth process. The inverted type mold is used throughout the world and is commonly accepted as being better qualified to produce quality ingots than the large-end-down type of mold.

The large-end-down type of ingot works out more economically than the inverted type, having less top discard, and for many applications the large-end-down ingot has advantages in processing. However, in making turbine spindles, particularly of alloy steel, the inverted ingot works out better. Ingots used in the forging of spindle and rotor shafts are generally of the corrugated type or the octagon type.

## • Preparation of ingot for forging

The processing of the ingot through the heatings preparatory to forging is very important. There are two ways of doing this. One is to strip the ingot from the mold after solidification, but while the ingot is still hot, and then pass it to an equalizing furnace where the cooling strains are equalized by maintaining a temperature of approximately 1250 F until complete equalization has taken place.

The ingot can then be heated to forging temperature, with ample time being allowed for complete saturation at the forging temperature before forging is started. There are many details in the forging operation, but needless to say the pressures of upsetting and reduction must be controlled at all times so that the material continuity is never jeopardized by drastic forging.

Another method of preparation of the ingot for forging is to allow it to become cold in the equalizing furnace after equalization is obtained and then store it for future use or until such time as the ingot is needed for preheating prior to transferring to the high temperature forging furnace. All operations must be carefully studied and controlled because of the possibility of losses that may occur if proper procedures in heating such large masses are not followed.

## • Forging

Depending upon forging facilities available, the ingot may be either upset from an ingot of smaller diameter than would permit proper forging reductions or the ingot may be of such a diameter as to permit reductions in areas of from 1.6 to 1 or 2 to 1. Greater forge reductions than these tend to result in loss of physical strengths in the radial or transverse test bars.

Most spindle and rotor shafts are forged on a steam hydraulic press. The press must be of sufficient magnitude to exert pressures great enough to cause working of the material to the core. Lack of this ability to deep-work the material results in loss of physical characteristics at the core, which is entirely unsatisfactory for forgings operating under rotational stresses.

One of the advantages of the alloy steels mentioned previously is that, under normal forge reductions, material of high physical test may be devel-

oped deep into the body of the forging. The requirement for perfect balance in the operation of a spindle or rotor is of such vital importance that great care must be exercised to obtain uniform radial heat saturation in the ingot and to forge the ingot concentrically, maintaining the chemical center of the ingot so that it occupies the same position as the mechanical center when the forging is operating as a part of the turbine. Any great deviation from these requirements can be detected in the lack of balance of the operating part.

## • Cooling from forging

It is necessary to exercise the same precautions in cooling a spindle or rotor from forging as it is to heat the ingot preparatory to forging. The forging must be shielded from all draughts and cooled slowly. Some of the high creep-resistance alloys have a transformation or grain change in the elastic range; hence the necessity of slow cooling to reduce the differential stresses set up in cooling from the outside into the core. If the outside cools rapidly while the core is still in the plastic state, the differential stress somewhere between the elastic state and the plastic state may be greater than the strength of the material at this location, and a burst or separation of the material occurs.

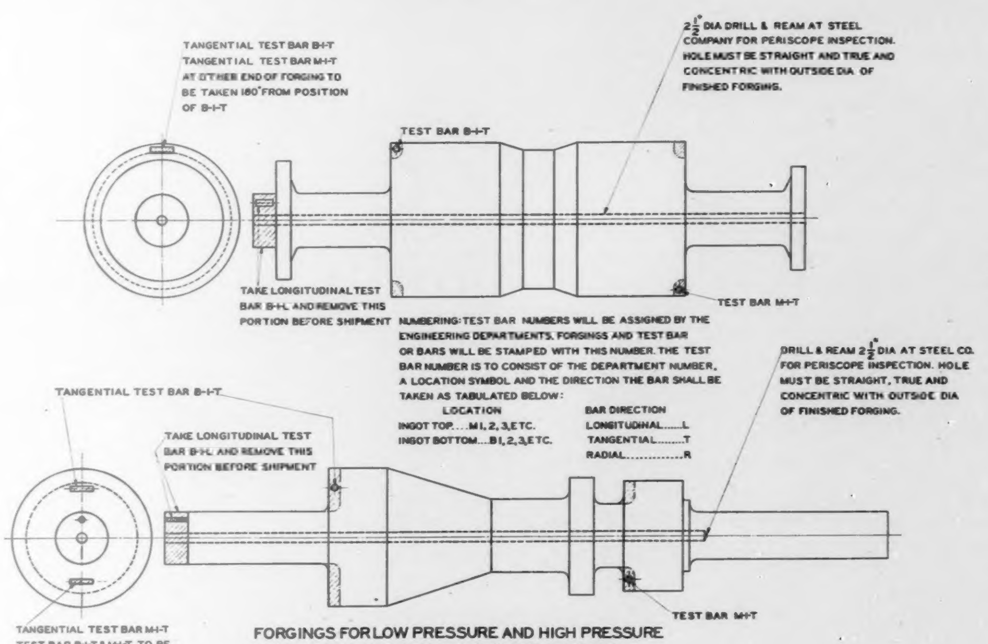
AT LEFT: Completed low pressure spindle, with blading in place, ready for assembly.

## • Normalizing

The objects of normalizing are to condition any abnormality of grain or structure incidental to forging practice, to equalize the structure, and to remove any traces of primary structure. It also places the microstructure in a position that is readily responsive to further annealing or heat treatment. This consists of "heating iron-base alloys to approximately 100 F above the critical temperature range, followed by cooling to below that range in still air at ordinary temperature." Spindle and rotor forgings are given this treatment preparatory to rough turning and boring.

## • Machining

In the several machining operations during the rough turning and boring operations, it is very important that centers be carefully laid out. In the




FORGINGS FOR LOW PRESSURE AND HIGH PRESSURE SPINDLES SHOWING HOLE BORED FOR PERISCOPIC INSPECTION AND POSITION OF TEST BARS

Fig. 2

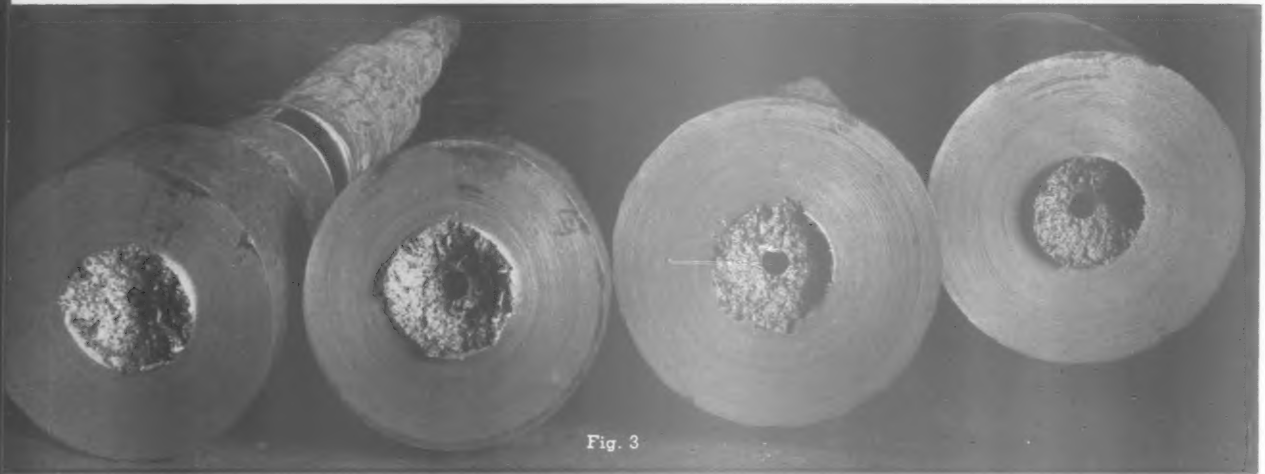


Fig. 3

event of any slight eccentricity between the body of the forging and the spindle arms, it is more important to center the shaft so that the body or larger diameters are concentric with the chemical center. This is necessary because of the effect of centrifugal stresses in operation and the influence of irregularities in homogeneity of material at increment distances from the center to the outside of the forging.

Several irregularities in both static and dynamic balance and operating balance have been attributed to either eccentric forging or eccentric machining with respect to the chemical center.

## • Annealing

Strict attention must be given to the annealing operations, as it is during these operations that the maximum physical results and microstructure are obtained. Transformation points affecting the microstructural changes which determine the treatment temperatures and the required time of holding the forging in the furnace are determined either by running a dilatrometric curve on a small piece of the material of the forging or by calculating the transformation temperatures by the use of an empirical formula derived from research. In the latter method, it is necessary to know the chemistry of the material as to carbon, manganese, silicon, sulphur, phosphorus, or any alloy present.

The forging is then subjected to annealing and heat treatment, with uniform application of heat and uniform saturation being maintained at all times.

Usually the annealing in the critical range of the material is followed by a low temperature treatment, commonly called the "spheroidizing treatment." This treatment is used to increase the ductility without materially decreasing the elastic properties.

## • Physical testing

Usually on spindle forgings the engineer is interested in the physical properties obtained at points tangential to the body of the forging. Sometimes radial tests are included from the body, and the spindle ends or reduced sections call for a longitudinal bar.

No forging is accepted on physical tests alone, but rather the information derived from both the physical test and the corresponding microstructure is used to determine the acceptance or rejection of a forging.

## • Semi-finish machining

After acceptance of the forging based on physical test and microstructure, the shaft then goes to the semi-finish boring and machining operations. These machining operations are generally done with a round-nose, semi-finishing cutter or tool in order that minute inspection may be given to the external surface and bore surface for examination for cracks, seams, ghosts, inclusions of any nature, or flakes.

Besides visual inspection, the bore is inspected with a periscope or boroscope. Concentricities are checked with respect to bore and turn.

## • Stress relieving

During the semi-finishing operations, there are minute surface stresses set up because of machining. In order to relieve these surface stresses before the forging goes into operation, it is necessary

to stress relieve the forging by heating it to a temperature above the operating temperature of the turbine but lower than that of the last treatment temperature given the forging. By this procedure any possible stresses remaining in the forging after machining are relieved, and since the stress relieving temperature was below the previous heat treatment temperature, the physical results obtained from the heat treatment remain unchanged. After the stress relieving treatment has been given, the spindle is usually stable with a minimum possibility of unbalance during operation of the turbine.

## • Finish machining

In the finish machining operation the small amount of stock left on the surface of the forging is removed, and the shaft is finished to drawing sizes. The fillets and radii are polished, and the dimensions finally checked preparatory to blading. Fig. 1 shows a high pressure spindle ready for blading.

During these finishing operations the surface is again inspected to guard against both metallurgical and physical surface defects.

## • Inspection of forgings

As indicated in the previous part of this paper, the inspection and checking of the forging to determine its suitability are very important. Each forging has a hole bored through its center as indicated in Fig. 2, which represents the forgings for a large 3600 rpm condensing steam turbine operating at 1290 lb steam pressure, 925 F steam temperature, and 29 in. vacuum.

The hole through the center of the forging must be finished smooth in order that a careful inspection of metal surfaces may be made. If there are any flaws such as cracks or cavities, it will usually be rejected. In some cases, however, it is permissible to remove these flaws by increasing the diameter of the bore. Surfaces having some minute inclusions can either be re-machined or, in some cases, these spots can be removed by grinding and polishing; but care must be taken to assure a gradual and smooth radius approach in all directions up to the point where imperfection exists.

Bursts or cavities are generally caused by too rapid heating or cooling, invariably occur in the center of the forging, and are, therefore, in some cases, discovered when the center hole is bored (see Fig. 3). If the burst or cavity occurs outside the center and is not discovered when the hole is drilled, it is usually discovered because of the unbalance of the finished spindle. Any imperfection existing on the outside surface of the forging can be detected by the use of the Magna-Flux nondestructive method of inspection.

The physical examinations mentioned before consist not only of checking the strength and ductility of the steel but also the actual grain structure. Figs. 4 and 5 show the final accepted grain structure in two types of steel. Normally the final grain structure is obtained without having to repeat any of the heat treatments. However, if the grain structure is not satisfactory it is in some cases necessary to re-heat-treat the forging.

While this discussion outlines the present practice of making suitable forgings for steam turbine spindles, it can be expected that the procedure will be changed from time to time as modifications and new discoveries are made in the chemical composition of steel and its alloys.

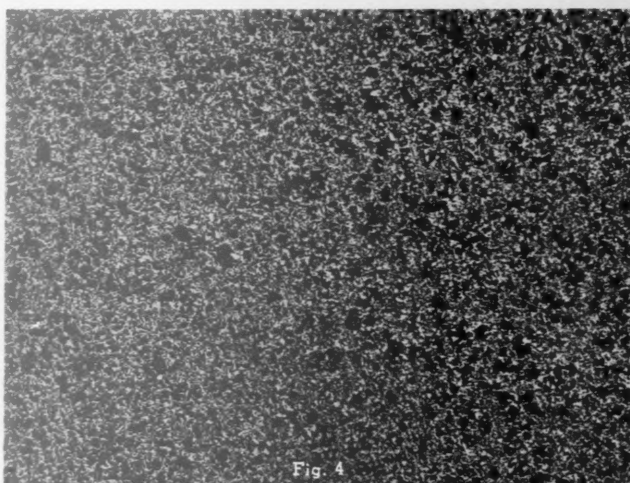


Fig. 4

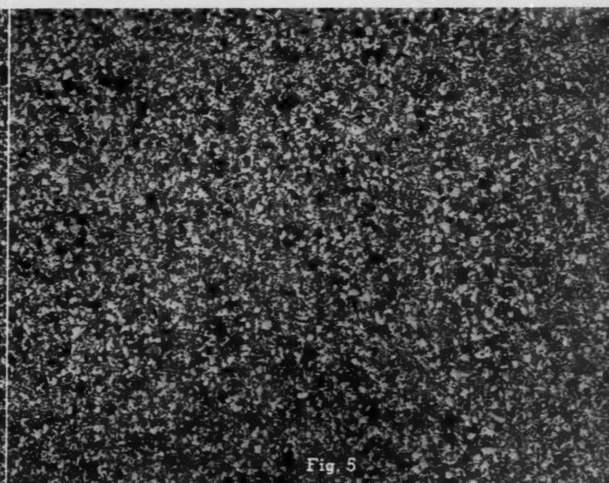


Fig. 5

# THE CIRCLE DIAGRAM AND THE INDUCTION MOTOR

• Fraser Jeffrey
A-C ENGINEERING DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

PART II*

For those types of motors that have a very high primary impedance drop or that have a copper loss at no-load that is large compared to the total no-load loss, it is necessary to modify the simple type of circle diagram shown by Fig. 4† to some extent.

It is assumed that there is no saturation of the magnetic circuit and that the rotor is not of the deep bar type.

Referring to Fig. 9,

1. Draw $I_oL$ parallel to OM at a distance $I_w$ above OM, where $I_w$ is found from equation (4)†. (Windage and friction loss may be handled as described in Appendix I, if desired, but for simplicity is not considered in this particular case.)
2. Draw $I_o'P$ parallel to OM at a distance $I_w'$ above OM, where

(32) $$I_w' = I_w - \frac{1.5\, I_o^2 R_p T_s k_s}{E\sqrt{3}}$$

3. Using O as a center, scribe the magnetizing current $I_o$ to intersect $I_oL$ at $I_o$ and $I_o'P$ at $I_o'$.
4. Using O as a center, scribe the short-circuit current $I_{sc}$, and on it locate the point $T_{sc}$ at a distance $W_{sc}$ above OM.

(33) Let $\Phi_o' = \cos^{-1} \dfrac{I_w'}{I_o}$

(34) and $\Phi_{sc} = \cos^{-1} \dfrac{W_{sc}}{I_{sc}}$

(35) and let $X_p + X_s$ = primary + secondary reactance (per leg) $= \dfrac{E}{I_{sc}\sqrt{3}} \sin \Phi_{sc}$

5. Lay off a line $I_o'N$ which makes an angle $\Theta$ with $I_o'P$, where

(36)‡ $$\tan \Theta = \frac{I_o\sqrt{3}\left[\frac{R_p}{2} + (X_p + X_s) \cos \Phi_o'\right]}{E}$$

The base of the circle is $I_o'N$, which is tilted at an angle in proportion to the amount of primary impedance, from the base line OM.

6. Draw a semicircle passing through points $I_o$ and $T_{sc}$ and having its center, $C_{sc}$, on line $I_o'N$.

$W_{sc}$, the power component of short-circuit current, is composed of core loss and stator and rotor copper losses and any stray losses that may be present. The rotor copper loss can be found by subtracting the other losses as follows:

The rotor $I^2R$ in kw with short-circuited locked rotor

(37) $$= \frac{W_{sc} \times E\sqrt{3}}{1000} - \frac{1.5\, I_{sc}^2 R_p T_s k_s}{1000} - \text{kw core loss}$$

The locked rotor starting torque is

(38) $$\text{synchronous hp} = \frac{\text{kw rotor } I^2R}{0.746}$$

For any load point such as "a," Fig. 9, the characteristics can be found as follows:

primary current (amperes) = Oa

(39) $$\text{kw input} = \frac{af \times E\sqrt{3}}{1000}$$

(40) $$\%\ \text{power factor} = \frac{af}{Oa} \times 100$$

(41) $$\text{stator } I^2R\ (\text{kw}) = \frac{1.5\, Oa^2 R_p T_s k_s}{1000}$$

(42) $$\text{rotor } I^2R\ (\text{kw}) = \left(\frac{I_oa}{I_oT_{sc}}\right)^2$$

(locked rotor $I^2R$ from eq. (37) )

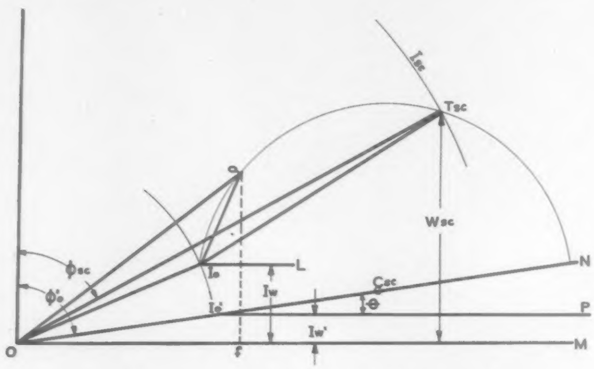
(43) kw output = kw input − stator $I^2R$ − rotor $I^2R$ − windage and friction loss − core loss

AT LEFT: Drilling a condenser tube sheet.

* Part I of "The Circle Diagram and the Induction Motor" appeared in the September, 1939, issue of the Allis-Chalmers ELECTRICAL REVIEW.

† Part I.

‡ H. C. Specht "A Practical Vector-Diagram for Induction Motors" in the ELECTRICAL WORLD AND ENGINEER, Vol. 45, No. 8, Feb. 25, 1905, pp. 388 to 394.




CIRCLE DIAGRAM OF THE HIGH PRIMARY IMPEDANCE MOTOR
Fig. 9

(44) $\text{hp output} = \dfrac{\text{kw output}}{0.746}$

(45) $\%\ \text{efficiency} = \dfrac{\text{kw output}}{\text{kw input}} \times 100$

(46) $\%\ \text{slip} = \dfrac{\text{kw rotor } I^2R}{\text{kw output}} \times 100$

or more accurately,

$$\%\ \text{slip} = \frac{\text{kw rotor } I^2R}{\text{kw output} + \text{kw windage and friction loss} + \text{kw rotor } I^2R}$$

(47) $\text{lb ft torque} = \dfrac{\text{hp output} \times 33000}{2\pi \times \text{actual rpm}}$

## • Performance of double squirrel cage motors

There is a type of induction motor to which the circle diagram method of determining performance does not readily apply. This is the type that uses a high reactance rotor of the double squirrel cage type, which has a current diagram similar to that shown in Fig. 10. It is apparent that the diagram is a combination of two circles, and for this reason a simple graphical method for determining the characteristics of this type of motor is not available.

The characteristics of such a machine can best be determined by taking a complete speed-torque curve from standstill to full synchronous speed.

## • Appendix I

Various approximations are involved in the simple circle diagram described in this article even when considering the ideal type of motor not having any saturation and having shallow rotor bars and low primary impedance.

The core loss is assumed constant from synchronous speed all the way to standstill. The variation in core loss is a complex phenomenon. Consequently, it is difficult to take the variation into account accurately. This variation combined with the variations in windage and friction loss, stray loss, and magnetizing copper loss may be very small, and except in unusual cases will seldom cause serious discrepancy.

A further assumption is made that the magnetizing current is constant from synchronous speed to zero speed, but, because of the variation in leakage fluxes that occurs with different loads at different speeds, this is not exactly true. Such a variation is another complex phenomenon that would be difficult to take into account accurately and usually should not cause any large discrepancy.

The windage and friction loss is also assumed as being constant from synchronous speed all the way to standstill and, strictly speaking, should not be included in the no-load losses below the base of the circle; for it is included in the power transferred across the air gap to the rotor. Also, it will be noted from Fig. 4† that, for any given load current, the no-load stator copper loss has been taken into account twice, since it is included in $I_w$ below the base of the circle; but the no-load current also accounts for a part of the loss $S_{sc}$ with locked rotor, or for a part of the stator copper loss for any given load point such as cd.

These discrepancies may be of negligible importance in most instances. Consideration may be given to some of these where the windage and

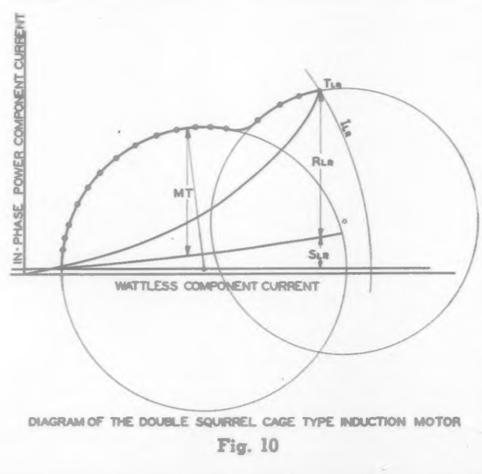



DIAGRAM OF THE DOUBLE SQUIRREL CAGE TYPE INDUCTION MOTOR
Fig. 10

TABLE 1—SEGREGATION OF LOSSES AND CONVENTIONAL EFFICIENCY

| ITEM | | POINT "a" [(Nos.)—Equations in Text] | POINT " " ___ |
|---|---|---|---|
| 1 | Stator Amperes (from Fig. 4) | Oa | |
| 2 | Rotor Amperes (if slip ring type) | (24) | |
| 3 | % Slip | (16), (21) | |
| 4 | RPM | Syn. rpm — slip rpm | |
| 5 | Stator Copper Loss @ 75 C (except using Oa in place of $I_{sc}$) | (7) | |
| 6 | Rotor Copper Loss @ 75 C | (11), (12), (23), (25) | |
| 7 | Brush Contact Loss (if slip ring type) | (26) | |
| 8 | Core Loss | (2) | |
| 9 | Windage and Friction | From Fig. 2 | |
| 10 | Total Loss, KW | 5+6+7+8+9 | |
| 11 | Output, KW | (10)×0.746 | |
| 12 | Input, KW | 10+11 | |
| 13 | % Conventional Efficiency | $\frac{11}{12}\times 100$ | |
| 14 | HP Output | (10) | |
| 15 | % Power Factor (quantities from Fig. 4) | $\frac{af}{Oa}\times 100$ | |

Fig. 11

friction loss is unusually large compared to the machine rating and where the no-load current is unusually large compared to the diameter of the circle.

Let $I_w$ be found from equation (4)†.

$$(48)\quad \text{Let } I_w' = I_w - \frac{\text{kw windage and friction loss at full speed}}{E\sqrt{3}} \times 1000$$

$$(49)\quad \text{Let } I_w'' = I_w' - \frac{\text{kw idle copper loss}}{E\sqrt{3}} \times 1000$$

Lay off lines $I_o'P$ and $I_o''Q$ at distances $I_w'$ and $I_w''$, respectively, above the base line OM, as shown in Fig. 12. Locate the no-load and short-circuit points $I_o$ and $T_{sc}$ in the usual manner. Draw the circle to pass through points $I_o$ and $T_{sc}$ but with its center $C_{sc}$ on line $I_o'P$, and let $I_o'$ be the point of intersection of the circle with the line $I_o'P$.

Lay off the distance $S_{sc}$ (from equation (6)†) above line $I_o''Q$, as shown; $R_{sc}$ is then the remainder of the short-circuit input.

$$(50)\quad R_{sc} = W_{sc} - I_w'' - S_{sc}$$

Draw the line $I_o'T_{sc}$, and draw $I_o'N_{sc}$ through the division point between $S_{sc}$ and $R_{sc}$.

Select any load point "a" and refer to Fig. 12. The air gap power output is represented by the distance ab; from this must be subtracted the windage and friction loss at that point to obtain the shaft output. The windage and friction loss, expressed in terms of power component amperes, varies from $I_w - I_w'$ at synchronous speed to zero at standstill. If a curve $I_oT_{sc}$ be drawn in such a manner that its distance above the line $I_o'T_{sc}$ at any load point is equal to

$$(51)\quad bg = \frac{\text{kw windage and friction loss at speed corresponding to load point}}{E\sqrt{3}} \times 1000$$

the output can be scaled between this curve and the circle. Since the speed falls off very little until

† Part I.

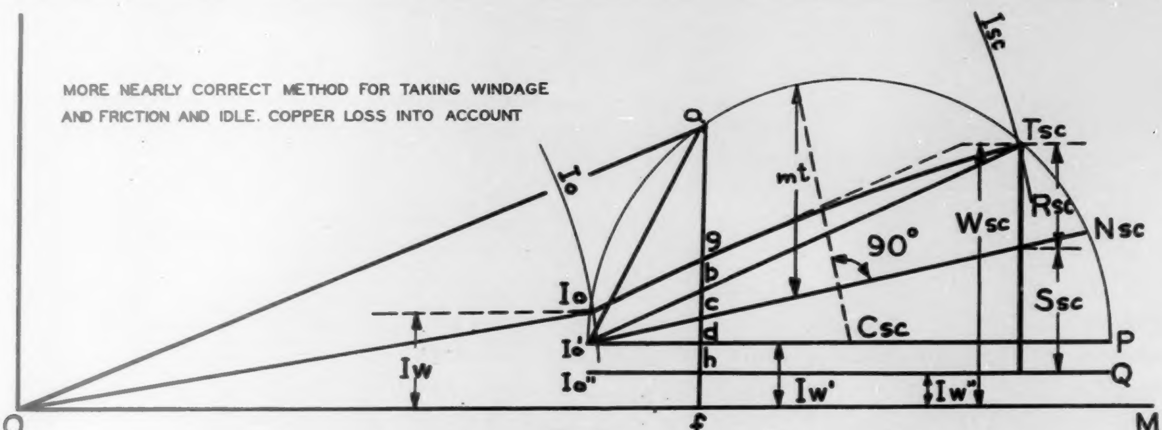



Fig. 12

a point quite far out on the circle is reached, the lower portion of the curve is very nearly a straight line parallel to $I_o'T_{sc}$. The upper portion beyond the straight line portion is not ordinarily required for obtaining the performance characteristics in the operating range.

The performance can be calculated as follows:

(52) maximum torque (synchronous hp)

$$= \frac{(mt \times E\sqrt{3}) - (T_{WF} \times 1000)}{746}$$

where $T_{WF}$ = torque of windage and friction loss, synchronous kw, at the speed at which the maximum torque occurs

(53) $T_{WF}$ = kw kindage and friction loss at that speed $\times \dfrac{\text{synchronous rpm}}{\text{actual rpm}}$

(54) static starting torque (synchronous hp)

$$= \frac{R_{SC}\, E\sqrt{3} - T_{BF} \times 1000}{746}$$

where $T_{BF}$ = static bearing friction torque, synchronous kw, which can be obtained by means of a beam bolted to the coupling flange

$$(55)\quad T_{BF} = \frac{\text{lb ft static bearing friction} \times \text{synchronous rpm}}{7040}$$

$$(56)\quad \text{hp output} = \frac{ag \times E\sqrt{3}}{746}$$

$$(57)\quad \%\ \text{efficiency} = \frac{ag}{af} \times 100$$

(58) lb ft torque =

$$\frac{(ac \times E\sqrt{3}) - (T_{WF} \times 1000)}{746} \times \frac{33000}{2\pi \times \text{synchronous rpm}}$$

or equation (17)† may be used.

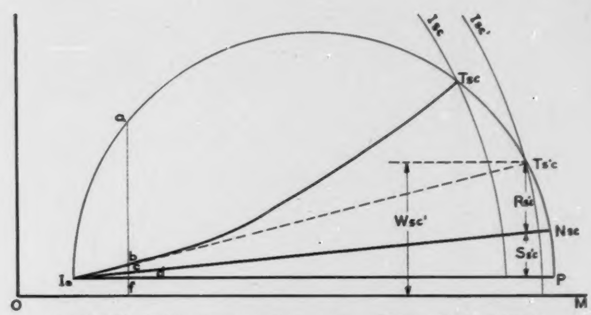
The rotor copper loss may be found from equation (11)† or from the following equation:

$$(59)\quad R_{c1} = \frac{R_{SC}\, E\sqrt{3}}{1000}\left(\frac{I_o'a}{I_o'T_{sc}}\right)^2$$

or, if a test curve of slip is available,

$$(60)\quad R_{c1} = \frac{(\text{hp output} \times 0.746 + \text{kw windage and friction loss}) \times \%\ \text{slip}}{100 - \%\ \text{slip}}$$

Completing the assembly of a large jaw crusher.




CIRCLE DIAGRAM FOR MOTOR WITH DEEP BAR ROTOR
Fig. 13

or, for a slip ring motor, equations (25)† and (27)† may be used, provided that the secondary current is taken as

$$(61)\quad I_s = \frac{I_o'a \times E}{E_2}$$

The stator copper loss can be found from equation (7)†, except using Oa in place of $I_{sc}$. It will be noted that approximately

$$(62)\quad S_{c1} = \frac{ch \times E\sqrt{3}}{1000}$$

The construction is such as to make this equation exact at the points $I_o'$ and $T_{sc}$. It is only slightly in error for other load points, but the use of equation (7)† gives more accurate results.

The input, power factor, and slip can be found from equations (13)†, (15)†, and (16)†, which remain unchanged.

## • Appendix II

In making the short-circuit test in the manner described, that is, by blocking the rotor, the locked rotor impedance, being measured with identical frequency in the stator and rotor, does not exactly represent the true impedance of the motor throughout its working range. The method described is accurate in cases where the rotor resistance does not vary greatly between zero frequency and rated stator frequency.

The method shown in Figs. 3† and 6† for determining the points $I_{sc}$ and $W_{sc}$, by extrapolating the lower voltage short-circuit points in a straight line

† Part I.

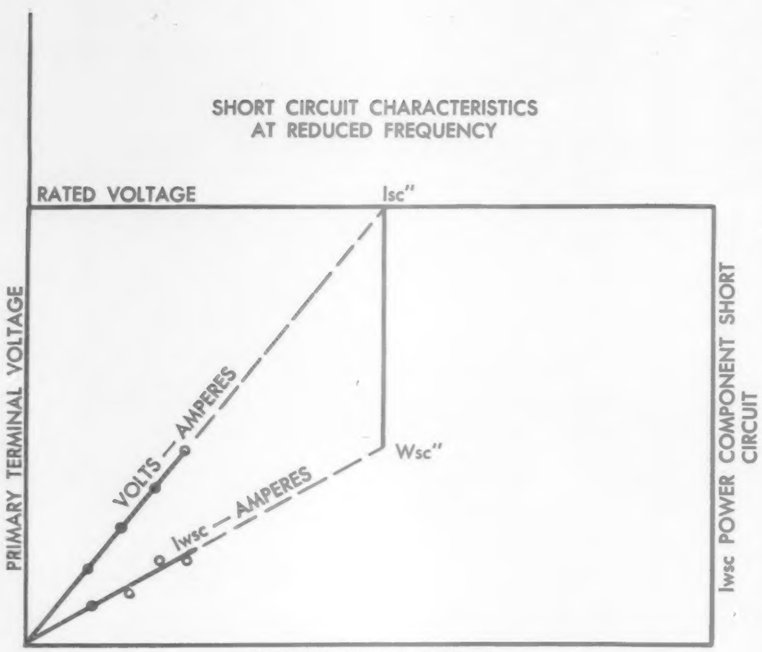


Fig. 14

in order to obtain the true running conditions of the motor, will not give satisfactory results for a motor having a deep bar rotor. In such cases the line $I_oT_{sc}$ in Fig. 4† is no longer a straight line but assumes the shape illustrated by Fig. 13. A complete load test from standstill to full speed would be necessary to establish the full curve $I_oT_{sc}$, but it will be noted that the part of the curve needed for obtaining the performance data in the working range is a straight line, which is shown extended in Fig. 13 as $I_oT_{sc}'$.

The points $I_{sc}''$ and $W_{sc}''$, Fig. 14, and $T_{sc}'$, Fig. 13, can be obtained by means of a short-circuit test at reduced frequency. The values $I_{sc}'$ and $W_{sc}'$, obtained as explained below from $I_{sc}''$ and $W_{sc}''$, will check the values $I_{sc}$ and $W_{sc}$ in Figs. 3† or 6†, and point $T_{sc}'$ will check point $T_{sc}$, Fig. 4†, for standard machines. For deep rotor bar machines, however, the method outlined below should be used.

Let $I_{sc}''$ and $W_{sc}''$ be the short-circuit current and its power component respectively, each extrapolated to rated voltage, at some reduced frequency (see Fig. 14). Then let

$$(63)\quad I_{sc}' = \frac{(I_{sc}'')^2}{\sqrt{(W_{sc}'')^2 + (\frac{f}{f_t})^2\,[(I_{sc}'')^2 - (W_{sc}'')^2]}}$$

$$(64)\quad \text{and } W_{sc}' = \frac{(I_{sc}'')^2 W_{sc}''}{(W_{sc}'')^2 + (\frac{f}{f_t})^2\,[(I_{sc}'')^2 - (W_{sc}'')^2]}$$

where $f_t$ = reduced frequency of short-circuit test

$f$ = rated stator frequency

The point $T_{sc}'$ is then plotted as before, using $I_{sc}'$ and $W_{sc}'$ in place of $I_{sc}$ and $W_{sc}$, and the circle drawn through $I_o$ and $T_{sc}'$ (see Fig. 13). The output is now measured between the circle and line $I_oT_{sc}'$ (ab is the output in Fig. 13). The line $I_oN_{sc}$ is located by finding $S_{sc}'$ from equation (6)†, using $I_{sc}'$ in place of $I_{sc}$. The running characteristics are then found in the same manner as before.

The starting current and starting torque must be obtained from point $T_{sc}$, found from a short-circuit test at normal frequency. If the bar is deep enough so that the rotor reactance as well as the rotor resistance is appreciably affected by frequency, points $T_{sc}$ and $T_{sc}'$ will no longer lie on the circumference of a single circle (see Fig. 10).

The frequency used in making the short-circuit test at reduced frequency depends upon the depth of the rotor bars and the accuracy required. Fifteen to 25 cycles on a 60 cycle machine will usually give good results on ordinary machines.

† Part I.

# 7 HARD YEARS ON THE JOB WITH...

# NO TIME-OUTS

## FOR REPAIRS!

*Another true case history from the Allis-Chalmers files that proves* **"IT PAYS TO BUY THE EQUIPMENT THAT PAYS FOR ITSELF!"**

**Here's a Tip from President Walter A. Zinn, Milwaukee Western Malt Co., on How to Cut Motor Repair Bills! Find Out How Allis-Chalmers Can Bring You Savings in Your Plant . . . with the Equipment that Pays for Itself!**

OPERATING 24 HOURS A DAY AT The Milwaukee Western Malt Company plant . . . in air that's hot and humid . . . this Allis-Chalmers Lo-Maintenance Motor is typical of the 86 that were seven hard years on the job with no time outs for repairs!

If you were building a new addition to your plant . . . if you wanted to double your capacity . . . get a better product at lower cost . . . you'd want to be sure every piece of equipment you bought held up its end of the job . . . without stopping production . . . without running up excessive maintenance costs!

That's what Walter A. Zinn was looking for when he expanded his plant in 1932. And because Mr. Zinn, besides being president of the Milwaukee Western Malt Co., is also an engineer and had designed many of the new plant's production features . . . he was mighty particular about the motors he was choosing.

"When you turn out 2,600,000 bushels of malt a year," said Mr. Zinn, "you've got to keep production rolling. You can't afford time-outs for motor repairs. That's why I turned the motor job over to Allis-Chalmers.

### No Repair Bills!

"And I wasn't wrong by a long shot! In the seven years they have been running in my plant, the only thing those Allis-Chalmers Motors haven't given us is costly repair bills!"

That's what Mr. Zinn and hundreds of other executives say about Allis-Chalmers equipment. And that's what you'll say once you put it to work for you in your plant!

There's more to Allis-Chalmers equipment than the rating on the nameplate . . . more in extra value features . . . more in that mechanical sturdiness that means longer life and less servicing.

Benefit by Allis-Chalmers 90 years of advancing with industry! Call the production engineer in the district office near you. Let him show you how you can cut costs... improve your workers' comfort and safety . . . with the equipment that pays for itself!

1096A

*. . . 90 Years of Engineering Superiority Work for You When You Specify Allis-Chalmers!*

ELECTRICAL DIVISION

**ALLIS-CHALMERS**

MILWAUKEE · WISCONSIN